USAARL Report No. 2015-07

Aeromedical Evacuation Enroute Critical Care Validation Study

By Khalid Barazanji[1], Amy Eslinger[1,2], Dave Brown[3,4], George Hildebrandt[3,4], Chris Squire[1,2], Joseph Eddins[1], Lance Oldorf[3], Bobby Bowers[1], Ron Wilson[3,4], Jeff Warren[4]

[1]U.S. Army Aeromedical Research Laboratory
[2]NorthTide Group, LLC
[3]Medical Evacuation Proponency Directorate
[4]Navigator Development Group, Inc.

United States Army Aeromedical Research Laboratory

Enroute Care and Airworthiness Division

February 2015

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia, 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human participants

The USAARL Determination Official has determined that this activity does not constitute research as defined under the human subjects protection regulations, as it is not "a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge [32 CFR 219.102(d)]."

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
27-02-2015	Final	03-02-2014 - 16-12-2014

4. TITLE AND SUBTITLE
Aeromedical Evacuation Enroute Critical Care Validation Study

5a. CONTRACT NUMBER N/A
5b. GRANT NUMBER N/A
5c. PROGRAM ELEMENT NUMBER 611102

6. AUTHOR(S)
Khalid Barazanji, Amy Eslinger, Dave Brown, George Hildebrandt, Chris Squire, MAJ Joseph B. Eddins III, CPT Lance Oldorf, Bobby Bowers, Ron Wilson, Jeff Warren

5d. PROJECT NUMBER S15
5e. TASK NUMBER N/A
5f. WORK UNIT NUMBER ACE

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER
USAARL 2015-07

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Materiel Agency
1430 Veterans Drive
Fort Detrick, MD 21702-9232

10. SPONSOR/MONITOR'S ACRONYM(S)
USAMMA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Physical limitations to rendering critical care caused by space constraints in the medical interiors of current U.S. Army MEDEVAC helicopters are unknown. The objective of this study was to evaluate the adequacy of space available for care providers to perform advanced medical treatment on simulated critical care patients (manikins) in existing MEDEVAC aircraft—the UH-60 and HH-60. Phase 1 identified medical tasks that could not be satisfactorily accomplished by medics working with current litter configurations, and Phases 2 and 3 determined the adequate vertical litter separation required to complete each unsuccessful task. During Phase 1, three experienced flight medics served as test participants (TPs) and wore Xsens MVN motion capture suits while performing 43 critical flight paramedic-level medical tasks that were determined to be space-consuming. In stature, the TPs varied from a 2nd percentile female to a 99th percentile male. (continued)

15. SUBJECT TERMS
MEDEVAC, helicopter, UH-60, HH-60, human factors, critical care management, limiting factors

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLAS	UNCLAS	UNCLAS	SAR	140	Loraine St. Onge, PhD
					19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

Reset

Abstract (continued)

Approximately 75 percent of the medical tasks were successfully accomplished by TPs working in the UH-60 Interim Medical Mission Support System, while 91 percent of the tasks were successfully completed in the HH-60M medical interior. Problems completing the medical tasks were due to structural physical limitations of the aircraft interior, primarily vertical clearance. When providing care to simulated patients on the UH-60 cabin floor ("slick" configuration), TPs completed 96 percent of the medical tasks. Neck and back bend angles were calculated from the motion data. The 2nd percentile TP's neck angle was 66 degrees, on average, for 94 percent of the time during all her tasks and scenarios. This angle is above 30 degrees flexion, which is considered a critical bend angle for potentially causing musculoskeletal injuries. Surprisingly, the 99th percentile TP's neck angle was much lower (by 28 degrees), and back angle was slightly higher than the 2nd percentile TP, suggesting that TPs assumed complex postures to accomplish patient care tasks. The findings suggest that ergonomic specifications should be considered when designing vehicle medical interiors. The lateral and longitudinal space dimensions utilized in UH-60 slick, UH-60 IMMSS, and HH-60M medical interior configurations were 50 inches (in.) and 48 in., 44 in. and 94 in., and 43 in. and 82 in., respectively. During Phases 2 and 3, 17 TPs (ranging from 35th percentile female to 99th percentile male in stature) were tested to determine the minimum vertical litter spacing required to accomplish the medical tasks adequately. It is recommended that an improved IMMSS should have vertical clearance of 28 in. between the litters, with more urgent patients loaded in the lower litter position and less urgent patients in the upper litter position. For future medical litter support systems, this recommended vertical litter separation should be validated during operational settings such as aircraft vibration and night operation.

Acknowledgements

The authors would like to express their sincere gratitude to the following people for their contributions to this project:

- Mr. Joe Licina for his aeromedical input on the experimental design and considerations. He brought a wealth of experience, and his feedback was invaluable to the success of this study.
- Mr. Charlie Paschal for his funding support and feedback on the general conduct of this study.
- Mr. James (CJ) Inglis for his assistance with contract management and support.
- Dr. Marcy Helgeson and Ms. Amy Barrett for their superb editorial review of this report.

This technical manuscript was developed with funding from the U.S. Army Medical Research and Materiel Command.

Table of contents

Page

List of tables

List of figures

Introduction

The Product Manager for the Medical Evacuation (MEDEVAC) Mission Equipment Package (MEP) at the U.S. Army Medical Materiel Agency (USAMMA) requested that the U.S. Army Aeromedical Research Laboratory (USAARL) and Medical Evacuation Proponency Directorate (MEPD) conduct a study to (1) evaluate space limitations in the UH-60 Black Hawk helicopter and HH-60 MEDEVAC helicopter that might affect administration of enroute care by flight medics and paramedics, and (2) provide recommendations for improving the UH-60 litter system (i.e., Interim Medical Mission Support System [IMMSS]) with respect to vertical litter separation. This project, dubbed the Aeromedical Evacuation Enroute Critical Care Validation (E2C2) study, will help identify potential capability gaps and provide data to enable UH-60 aeromedical evacuation preplanned product improvement (P3I) programs with the IMMSS and HH-60M medical evacuation interior. These results will also support an ongoing capability-based assessment for both current and future aeromedical evacuation aircraft.

Background

Emergency vehicle design has evolved over the years with the use of modeling and simulation. In a joint project between the Madrid Technical University and the Medical Emergency Services of the Madrid Regional Government, a mathematical model was developed for optimizing the layout of an intensive care unit vehicle, taking into account critical and frequent medical interventions, personnel position and their actions, and materials and devices used (Alejo, Martin, Ortega-Mier, et al., 2009). It was not clear how the care providers were modeled, but the model elements were relevant to the present study.

In 1986, USAARL conducted a study to determine the vertical and lateral litter clearance required to perform basic medical procedures on board a UH-1 utility helicopter configured in a standard litter configuration (Mitchell & Wells, 1986). The study was in response to a directive from the Director of Combat Developments, U.S. Army Academy of Health Sciences (HSHA-CEDM, dated 7 Oct 85) requesting that USAARL "conduct an investigation and determine the desired and minimum standards for vertical and lateral separation of litters for providing Emergency Medical Technician (EMT) level care onboard *[sic]*Army aircraft on the integrated battlefield." In the study, one flight medic performed required medical tasks at three different litter heights, and the researchers moved the litters closer together until the medic could no longer complete the tasks. The 1986 USAARL study determined the previous litter vertical separation minimum of 18 inches (in.) (46 centimeters [cm]) based on a North American Treaty Organization (NATO) Standardization Agreement (STANAG) 3204 (NATO, 1999), was insufficient to perform combat-related EMT tasks while transporting unstable patients and performing life-saving medical tasks. The researchers determined that the minimum vertical separation required to achieve the required performance was 20 in. (51 cm), and the minimum lateral separation was 21 in. (53 cm) (Mitchell & Wells, 1986).

The American Society for Testing and Materials (ASTM) Working Group F30 for emergency medical services has produced a standard outlining the minimum requirements, including personnel and patient care equipment and supplies, for an aircraft to be classified as a rotary-wing air ambulance unit. The standard specifies that adequate cabin space shall be constructed to allow life support interventions at the head and upper body with a minimum rectangle of space, above the stretcher, free of all projections and encumbrances, 18 in. (45.7 cm) wide, 28 in. (71.1 cm) high, and 30 in. (76.2 cm) long. In addition, the standard specifies an additional contiguous envelope of space, 18 in. (45.7 cm) wide, 18 in. (45.7 cm) high, and 42 in. (106.7 cm) long to accommodate the lower extremities of the patient (ASTM, 2003).

The U.S. Army MEDEVAC Product Director at Project Manager, Utility Office in Huntsville, Alabama, laid out a strategic plan to address issues raised in after action reports (AARs) from Operations Iraqi Freedom and Enduring Freedom (Anderson, 2012). Two major issues related to this study were raised: (1) There is limited space available in the UH- and HH-60 to render enroute critical care, and (2) Current medical interiors contributed to crewmember fatigue and back injuries. This is a plausible concern, as posture been shown to play a clear role in care providers' injuries (Lester, Hsu, & Ahmed, 2012), and working several hours on repeated activities that require bending has been associated with back pain (Guo, 2002).

Enhanced medical treatment capabilities (e.g., enroute critical care nurses [ECCN], critical care flight paramedics [CCFP], advanced trauma management [ATM]) require an evacuation platform that enables efficient medical intervention while enroute to the next level of care. The 1986 USAARL study does not reflect the advanced medical practices, materials, or capabilities performed by combat medics, flight paramedics, or enroute care specialists in modern U.S. Army evacuation platforms. There have been no studies validating enroute patient treatment protocols for standard U.S. Army medical tasks while on board a UH-60A/L (Department of the Army [DA], 2009b), or the most current aeromedical evacuation platform for combat, the HH-60M (DA, 2009a).

Today's capability to perform life-saving inflight medical treatment on H-60 platforms has evolved from the UH-60A/L, which had no dedicated medical interior, to a purpose-built medical interior with specific features to enhance patient transport:

- Production of a medical evacuation kit utilizing a pedestal support assembly capable of supporting six litter patients or six ambulatory patients;
- Production of the IMMSS Patient Handling System supporting up to four litter patients or four ambulatory patients; and
- The HH-60M with factory integrated medical evacuation interior supporting up to six litter patients or six ambulatory patients.

Based upon these changes to the aircraft interior and the recently enhanced treatment capability provided by onboard paramedics, the MEDEVAC Enterprise requested that USAARL evaluate the adequacy of space available to the flight paramedic while performing critical lifesaving tasks on board the UH- and HH-60 aircraft, measured against approved protocols and scenarios.

Problem statement

Space constraints in the existing medical interiors of the UH- and HH-60 aircraft have created potential physical limitations to rendering effective enroute critical care.

Objective

The objective of the study was to evaluate the adequacy of space available for care providers to perform advanced medical treatment scenarios on simulated critical care patients (manikins) in existing MEDEVAC aircraft, i.e., UH- and HH-60. Specifically, the study provides:

- A list of medical tasks that cannot be accomplished within the currently provided occupiable space;
- A list of subject matter expert (SME) selected medical tasks that can be accomplished within the current space of the UH- and HH-60;
- A record of the vertical litter clearance needed to accomplish advanced medical treatment on board the UH-60 and HH-60.
- Recommendations for space dimensions required to perform CCFP Additional Skill Identifier "F2" tasks in the UH- and HH-60 (DA, 2013a).
- Space parameters used per medical task for each scenario;
- Video documentation of all tasks and scenarios;
- Interactive three dimensional (3D) imaging and mapping by the Navigator Development Group, Inc. contract team showing the space utilized to perform each task;

Methods

This study was performed in three phases. Phase 1 identified any inability of flight medics to perform critical medical tasks in current UH- and HH-60 litter configurations. Phases 2 and 3 sought to determine the vertical litter separation required to adequately complete each previously unsuccessful task and identified any other limitations caused by vertical spacing.

SMEs from MEPD and USAARL selected, from the full list of CCFP medical tasks (DA, 2013b), the most space-consuming medical tasks with the highest probability for impacting patient morbidity and mortality. All three phases used the resulting medical task list described in table 1.

Table 1.
Medical task list used in E2C2 study.

Task Number	Task Conducted
1	Load a casualty on to an H-60 helicopter
2	Open the airway
3	Insert an oropharyngeal airway
4	Insert a nasopharyngeal airway
5	Insert a King LT supraglottic airway
6	Intubate a patient
7	Perform a surgical Cricothyroidotomy
8	Perform endotracheal suctioning of a patient
9	Perform a needle chest decompression
10	Treat a casualty with a chest injury
11	Insert a chest tube
12	Administer initial treatment for burns
13	Perform rescue breathing
14	Ventilate a patient with bag-valve-mask system
15	Set up an oxygen tank (size D)
16	Perform oral and nasopharyngeal suction of a patient
17	Administer oxygen
18	Measure a patients pulse oxygen saturation
19	Measure a patient's blood pressure
20	Operate the Zoll M Series CCT (P/N 8000-0851-30) monitor/defibrillator
21	Operate the Zoll Propaq 206EL with $Sp0_2$ monitor
22	Operate the Carefusion Alaris® intravenous (IV) pump
23	Operate the Vital Signs enFlow IV fluid and blood warmer
24	Use the Special Medical Emergency Evacuation Device (SMEED™)
25	Measure a patients pulse
26	Measure a patient's temperature
27	Advanced cardiac life support
28	Initiate treatment for hypovolemic shock
29	Initiate an IV infusion
30	Initiate A FAST-I
31	Establish interosseous infusion
32	Apply a pressure dressing to an open wound
33	Apply a hemostatic dressing
34	Provide basic emergency care for an amputation
35	Apply a tourniquet to control bleeding
36	Treat a casualty with an open abdominal wound
37	Treat a casualty with an impalement
38	Treat a casualty with an open or closed head injury
39	Apply a cervical collar
40	Immobilize the pelvis
41	Immobilize a suspected fracture of the arm or dislocated shoulder
42	Apply a traction splint
43	Apply a Reel Splint Immobilizer™

Note: These tasks were selected as the most space-consuming critical medical tasks from the full list of CCFP medical tasks (DA, 2013b) See text for explanation.

Phase 1: Critical medical task performance in UH- and HH-60

Subjects

Three experienced flight medics served as test participants (TPs) and were designated TPs A, B, and C1. A fourth TP (C2) was designated as a backup TP to replace C1 because of scheduling conflicts. TP proficiency was validated by a qualified and combat-experienced U.S. Army Aeromedical Physician's Assistant medical validator (MV) in accordance with current CCFP standards (Military Occupational Specialty [MOS] 68W). Table 2 lists the anthropometric measurements of the TPs (Gordon et al., 1989). The percentiles referring to specific TPs throughout this report are based on TP height (stature).
.

Table 2.
Anthropometric measurements of TPs in phases 1 and 2.

Item	**TP A**	**TP B**	**TP C1**	**TP C2**
Gender	Male	Female	Male	Male
Percentile based on height*	>99th	2nd	80th	75th
Height (cm)	196.0	150.0	181.0	180.0
Foot (cm)	29.5	22.5	32.0	29.0
Arm span (cm)	204.0	150.0	182.0	173.0
Ankle height (cm)	11.0	8.3	7.0	8.0
Hip height (cm)	104.5	77.5	99.0	90.0
Hip width (cm)	25.0	20.0	23.0	25.0
Knee height (cm)	58.0	44.0	53.0	49.0
Shoulder width (cm)	40.5	30.5	38.0	42.0
Sole thickness (cm)	2.0	2.0	4.0	2.0
Weight (kilogram [kg])	99.8	61.2	77.6	90.7

*Gordon et al. (1989)

Equipment

Aircraft used during Phase 1 testing included: a UH-60 with no medical kit or interior, referred to as a "slick" configuration (e.g., UH-60 slick floor); a UH-60 configured with an IMMSS system; and an HH-60M with a medical interior. For each scenario, the following equipment was available: air ambulance medical equipment set (MES) items (table 3); one Xsens MVN inertial motion capture system (IMCS); and three GoPro® Hero3 cameras.

In Phase 1, TPs performed all assigned tasks while wearing an Xsens suit with a head mounted tracker (no helmet or Air Warrior personal survival gear carrier).

Xsens MVN IMCS

The Xsens MVN IMCS used in Phase 1 consisted of inertial sensors attached to the TP's body by a Lycra® suit. The Xsens MVN IMCS gave freedom of movement because the Xsens uses no cameras. This flexible and portable system was used indoors and outdoors. The Xsens MVN IMCS required minimal cleanup of captured data as there was no occlusion or marker swapping.

The Xsens motion capture (MoCap) was used to record human movement. The data were used to animate digital characters in a virtual environment in order to characterize a realistic human movement. MoCap was also used to analyze the TP's movement. The MVN motion capture suit, made up of 17 MTx inertial trackers that operated wirelessly for full freedom of movement, provided six-degrees-of-freedom tracking of the body. The system provided output from 23 body segments. The data were exported to popular motion capture file formats, such as .bvh and .fbx, for manipulation.

The Xsens MVN MotionGrid is a position aiding system for use with Xsens MVN IMCS. MotionGrid enables real-time driftless multiperson recording. It is portable and enables indoor and outdoor recordings. Large capture volumes of 20 by 20 meters (m) (60 by 60 feet [ft]) are realized using the default MotionGrid configuration. With a minimal amount of hardware and quick calibration, MotionGrid is a flexible and cost effective system. The MVN MotionGrid is based on ultra wide-band radio frequency technology; therefore, it did not require line-of-sight or special lighting conditions. MotionGrid essentially added the equivalent of a local global positioning system to the Xsens' MVN full body motion capture system. However, issues were discovered during prestudy testing that precluded the use of the MVN MotionGrid for this study. The system could not accurately collect data from motion sensors that were located behind a metal structure; i.e., the aircraft skin.

Medical equipment

Table 3 lists the MES items that were provided in the cabin of the testing platforms for use by TPs during each scenario.

<u>Table 3.</u>
Medical equipment used for the study.

Nomenclature	National Stock Number
Zoll M Series CCT (P/N 8000-0851-30) monitor/defibrillator	6515-01-515-4197
Zoll Propaq 206EL monitor with $Sp0_2$	6515-01-432-2707
Alaris Medsystem III with DLE (2865B) IV pump	6515-01-550-5669
Impact 326M suction	6515-01-435-0050
Impact 754M with reusable container ventilator	6530-01-464-0267
Medical aid bag	6545-01-518-8536
Oxygen bottle with regulator	6505-00-132-5181
Accu-check® Aviva glucometer	6630-01-596-3282
Vidacare® EZ-IO G3 Power Driver kit	6515-01-571-3152
Reel Splint Immobilizer™	6515-01-250-8936
Pluer-evac® chest drainage system	6515-01-499-3126
North American Rescue Perfit ACE® cervical collar	6515-01-541-8147
Pelvic Binder, Inc. pelvis splint	6515-01-560-0290
Vital Signs enFlow IV fluid and blood warmer	6515-01-553-0107
Verathon, Inc. GlideScope® Ranger video laryngoscope system	6515-01-572-7262
North American Rescue Armadillo medication storage case	8145-01-573-2533
H & H Associates Emergency Cricothyroidotomy Kit (individual)	6515-01-573-0692
Nonin Onyx® II 9550 finger pulse oximeter	6515-01-557-1136
Arrow International, Inc. jugular vein puncture kit	6515-01-262-7222
Argon Medical Corporation catheterization kit, cardiovascular	6515-01-227-3565
Estill Medical Technologies, Inc. Thermal Angel® TA-200 fluid warmer	6515-01-503-8228
Abbott Laboratories, Inc. i-STAT blood gas analyzer kit	6630-01-526-7377
Impact Instrumentation, Inc. Critical Care Platform (SMEED)™	6530-01-500-2305
North American Rescue long spine board	6530-01-490-2487

GoPro® Hero3 cameras

The GoPro® Hero3 cameras provided a small form factor combined with a wide field-of-view, which allowed for camera placement in areas with limited space. In addition, they provided high definition video (1080 pixels [1080p]) at up to 60 frames per second (s), and the ability to monitor the video feed remotely to ensure optimal camera placement in tight areas. The team used the cameras to capture video for each of the three phases.

Scenarios

Figures 1 through 8 show the eight different scenarios performed by the TPs on board two types of air ambulances (UH- and HH-60) configured in accordance with airworthiness release directives (DA, 2009a and b), mission requirements (MEPD), and lessons learned (AMEDD Center for Lessons Learned). A total of 22 scenarios were conducted:

- TP A: Scenarios 1, 2, 3, 4, 5, 6, 7, 8;
- TP B: Scenarios 1, 2, 3, 4, 5, 6, 7;
- TP C1: Scenarios 1, 2, 3; and
- TP C2: Scenarios 4, 5, 6, 7.

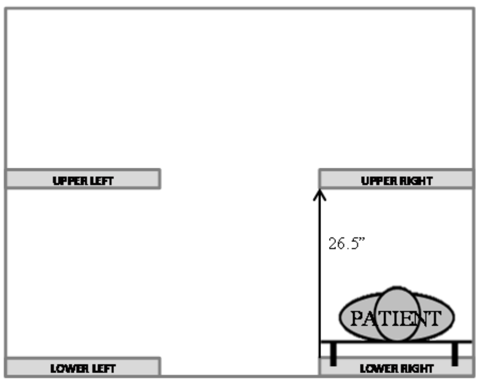


Figure 1. Scenario 1-aft view, UH-60 with IMMSS, one patient carry, treatment patient in lower right.

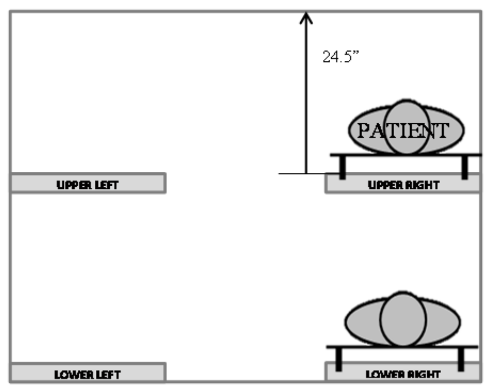


Figure 2. Scenario 2-aft view, UH-60 with IMMSS, two patient carry, treatment patient in upper right.

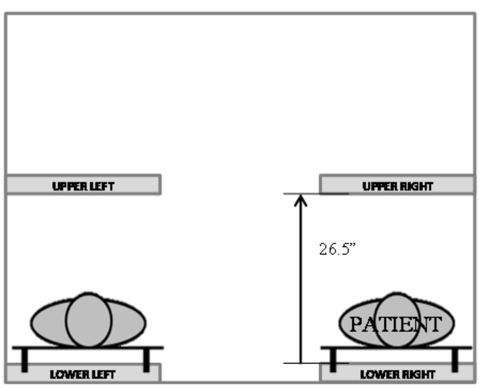


Figure 3. Scenario 3-aft view, UH-60 with IMMSS, two patient carry, treatment patient in lower right.

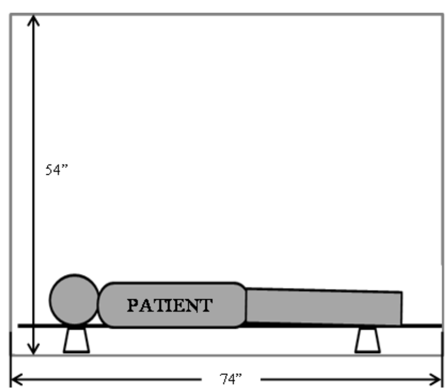


Figure 4. Scenario 4-aft view, UH-60 slick floor, one patient carry, treatment patient in load position.

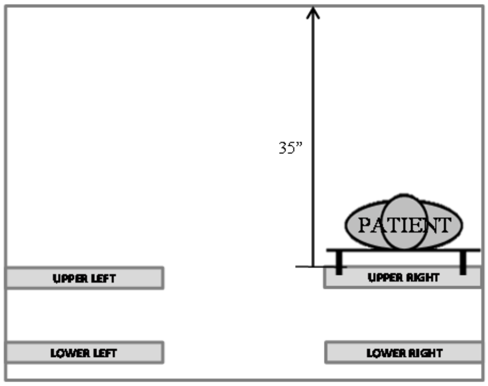


Figure 5. Scenario 5-aft view, HH-60M with medical interior, one patient carry, treatment patient in upper right.

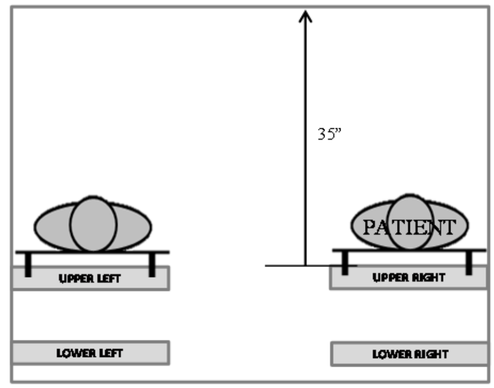


Figure 6. Scenario 6-aft view, HH-60M with medical interior, two patient carry, treatment patient in upper right.

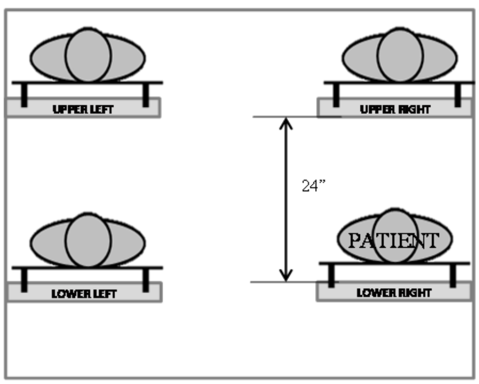


Figure 7. Scenario 7-aft view, HH-60M with medical interior, four patient carry, treatment patient in lower right.

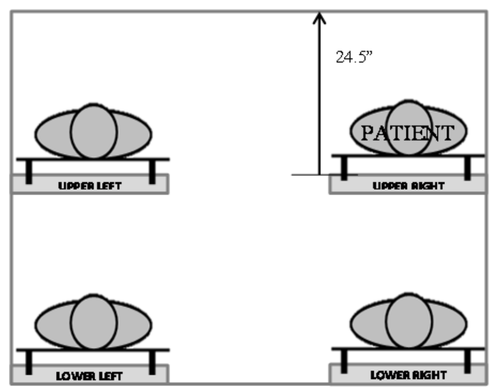


Figure 8. Scenario 8-aft view, UH-60 with IMMSS, four patient carry, treatment patient in upper right.

Scenarios 1 and 3 were similar to each other in terms of capturing the TP’s motion while performing the medical tasks on a patient in the UH-60 IMMSS lower right litter position. However, scenario 1 captured the TP’s motion while organizing medical equipment for one patient versus two patients in scenario 3. Those motions for placing medical equipment around the patient or TP were recorded but not analyzed because of time constraints and lack of a medical equipment placement standard. Scenarios 2 and 8 are also similar because the treated patient is located in the UH-60 IMMSS upper right litter position. Lastly, scenarios 5 and 6 are similar because of the treated patient in the upper right of the HH-60 medical interior. Appendix A contains detailed dimensions of each scenario.

The MV visually identified unsuccessful patient care tasks that occurred secondary to space-limiting constraints for each task tested. Unsuccessful patient care tasks were identified as the following:

- Task could not be completed because of physical restrictions imposed by limited space (designated in table 6 as “S”);
- Task was completed but not per a known or reasonably assumed clinical practice guideline (CPG) standard of care for a single caregiver. (e.g., the crew chief was used to lift and support the patient while the flight medic performed examination and treatment for the task “treat casualty with a chest injury”) (designated in table 6 as “A” for Caregiver requiring assistance); and
- Task completion resulted in an injury or a potential injury event incurred upon the patient or a potential injury event to the medic and/or untreated patient in an adjacent litter pan (designated in table 6 as “I”).

Data acquisition and analysis

A ten-step process was followed to acquire the desired data for this study (appendix B). Steps one and two included creating dimensionally accurate models of each TP, airframe, medical interior, and MES item by the interactive 3D (i3D) Navigator Development Group, Inc. development team to be used during the post-processing. These 3D models were created using Autodesk 3D Studio Max® (3DS Max®) and Autodesk Maya® and were developed using measurements obtained from engineering computer-aided design (CAD) data, aircraft operator manual technical manual (TM) 1-1520-237-10 data, measurements provided by USAARL, and hands-on measurements taken by the i3D Navigator Development Group, Inc. development team (Department of Defense [DOD], 2002).

TP motion was captured by utilizing the Xsens MVN IMCS in conjunction with Xsens MVN Studio software. Each TP wore the Xsens suit. The study team live-tracked the TP with Xsens MVN Studio, and filmed the TP with GoPro® cameras while the TP executed the required medical tasks as defined and observed by the MV. The MV took notes throughout each scenario regarding successful or unsuccessful completion of each task. As the live scenarios were completed, the team transferred the motion data and video footage to the i3D development team and video editor, respectively, for initial processing.

The motion data was then loaded back into Xsens MVN Studio for initial cleanup. This included hard-setting of floor heights, figure posture correction, and figure measurement validation. The video footage was consolidated and time-synchronized by the video editor using Adobe® Premier® software so that one high-definition (1080p) .mp4 was available per scenario containing all three synchronized camera views along with a minutes:seconds:frames timestamp for reference by the MV for defining exact start and stop times for each motion captured task. Once the motion data were refined and exported as .bvh files video footage was synchronized and exported as .mp4 files, and task times were defined within an Excel spreadsheet, all resources were provided to the i3D development team for continued development.

Upon receipt of the refined motion data, the i3D development team used a combination of Autodesk® Motion Builder, Maya®, and 3DS Max® to sequence and combine the individual .bvh

files containing refined motion capture data so that each scenario would have a single animation sequence. At that time, the motion capture sequences were applied to the 3D TP models and paired with the appropriate scenario aircraft, medical interior, and MES kit using 3DS Max.® The *x*-, *y*-, and *z*-axis positioning of the TP relative to world space can drift and produce inaccurate recordings. To address this issue, the i3D development team made manual corrections to *x*-, *y*-, and *z*-axis positioning within 3DS Max® using the synchronized video footage as a reference for placement within the virtual scene. This allowed true-to-scale playback of each captured scenario within the virtual scene to include accurate limb movements as well as accurate positioning relative to other items in the virtual space. All completed files were then exported to .fbx format for use within a custom real-time processing application.

The i3D development team created a customized motion data processing application based on specific requirements and study objectives. This application was developed using the Unity® software game engine and contained functions that allowed playback, review, volumetric 3D overlays, manipulation of data collection variables, and exporting of motion data to a tab-delimited text file for use within Excel, Matrix Laboratory (MATLAB), or other processing and analysis applications. As .fbx files were completed, the i3D development team imported those files into the application, performed basic configuration functions, then processed the data to provide *x*-, *y*-, and *z*-axis positioning data representative of the virtual TP movement; virtual TP neck and back angles using the aforementioned *x*-, *y*-, and *z*-axis data; and volumetric data representative of the space used by various body parts during each task execution.

The data processing application developed for this study provided a visual interface for viewing the captured data in a virtual 3D space largely representative of the real-world scenarios; however, it also provided the capability for virtual overlays allowing a greater and more immediate understanding of where space was most utilized by what body parts and for what specific purpose. Figure 9 shows an example of that overlay capability by displaying a 3D volume envelope of space dimension taken up by the hands during the procedure and a series of lines drawn in 3D space providing greater insight into the amount of time spent in specific areas.

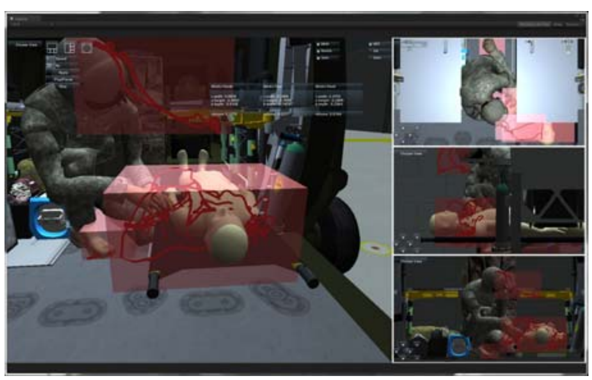


Figure 9. Envelope volume and tracked movement.

In addition to the visual component, the application was programmed to produce a series of three tab-delimited text documents containing raw data for importation into Excel, MATLAB, or

other data processing applications for further analysis. The first of these documents contains the *x*-, *y*-, and *z*-axis positioning data for 32 separate points tracked for each virtual TP. The following points were included: head with helmet top extent, forehead with helmet, head with helmet left extent, head with helmet right extent, head with helmet back extent, chin, neck, left shoulder, right shoulder, sternum, back extent, left elbow, right elbow, left wrist, right wrist, left finger extents, right finger extent, pelvis, front waist extent, rear waist extent, left waist extent, right waist extent, left hip, right hip, left knee, right knee, left ankle, right ankle, left toe extent, right toe extent, left heel extent, and right heel extent. Each point was recorded three times per second during playback and was represented along with the current task number, timestamp, and the *x*-, *y*-, and *z*-axis data as they relate to the origin of the scene (figure 10).

Time (Sec)	Task Number	Tracked Point	X Position	Y Position	Z Position	Ceiling Y Position: 53.82758
Floor Y Position: -0.2693944		Wall Left X Position: -57.21594		Wall Right X Position: 16.67779		
0.02	0	Head Top	60.71777	34.06365	80.53806	
0.02	0	Head Back	57.95226	32.95314	76.56506	
0.02	0	Head Front	63.05957	30.41325	83.93198	
0.02	0	Head Left	63.71989	29.24314	76.94319	
0.02	0	Head Right	56.2722	29.27727	82.11823	
0.02	0	Head Chin	61.52175	24.05981	81.54449	
0.02	0	Neck	58.92854	25.16699	371.0147	
0.02	0	Sternum	62.59139	16.39083	83.00316	
0.02	0	Upper Back	56.83327	16.50372	75.10752	
0.02	0	Shoulder Left	64.38176	21.6671	74.07027	
0.02	0	Shoulder Right	53.29841	21.6624	81.84505	
0.02	0	Elbow Left	69.82798	21.4158	70.29687	
0.02	0	Elbow Right	48.31057	21.43288	85.36993	
0.02	0	Wrist Left	76.5757	21.14898	65.69678	
0.02	0	Wrist Right	41.27314	21.10899	90.34322	
0.02	0	Hand Left	82.66609	21.16184	61.4144	
0.02	0	Hand Right	35.82142	21.43761	94.68068	
0.02	0	Pelvis	58.35363	4.39293	77.31025	
0.02	0	Waist Front	62.1288	6.380891	82.68657	
0.02	0	Waist Back	57.0455	6.902127	75.05875	
0.02	0	Waist Left	64.51203	6.746892	74.38708	
0.02	0	Waist Right	53.4147	6.755547	82.17459	
0.02	0	Hip Left	61.47034	4.399426	74.90211	
0.02	0	Hip Right	55.03028	4.396647	79.41997	
0.02	0	Knee Left	61.33762	-8.599387	74.72932	
0.02	0	Knee Right	54.9076	-8.602165	79.24103	
0.02	0	Ankle Left	61.02719	-22.1932	74.26926	
0.02	0	Ankle Right	54.58713	-22.19594	78.78702	
0.02	0	Heel Left	59.865	-25.7251	73.20336	
0.02	0	Heel Right	53.53085	-25.71199	77.71191	
0.02	0	Toe Left	65.44939	-25.7251	80.58492	
0.02	0	Toe Right	59.00033	-25.71199	85.08972	

Figure 10. Raw data showing time recorded and *x*-, *y*-, *z*-axis position for all points tracked during testing.

From the x, y, and z positions of the motion sensors, back and neck bends angles were determined (figure 11). Within the application, various thresholds can be set for these two HF parameters. As a default, a threshold of 30 degrees was set for both parameters (Golob & Sykes, 2002; Buckle & Devereaux, 2002; Chaffin, 1973). The generated documents contain the task number, task duration, minimum angle, maximum angle, average angle, quantity of bends exceeding threshold, duration exceeding threshold, and average angle above threshold for each task in each scenario.

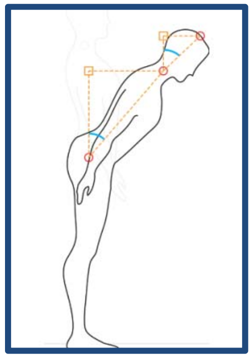


Figure 11. Neck and back angles.

The data detailing the volume of space taken up by each virtual TP during the execution of each required task is segmented in the following way to provide greater resolution on volumes used by specific segments of the body: head only, hands only, arms only, upper body, and lower body. The generated data contain the task number, tracked area, *x*-, *y*-, and *z*-axis of center point of envelope volume used, extents of the envelope volume on all three axes, and the cubic inches of the envelope volume used. This provides the input to populate the 3D volume cube envelope (figure 12).

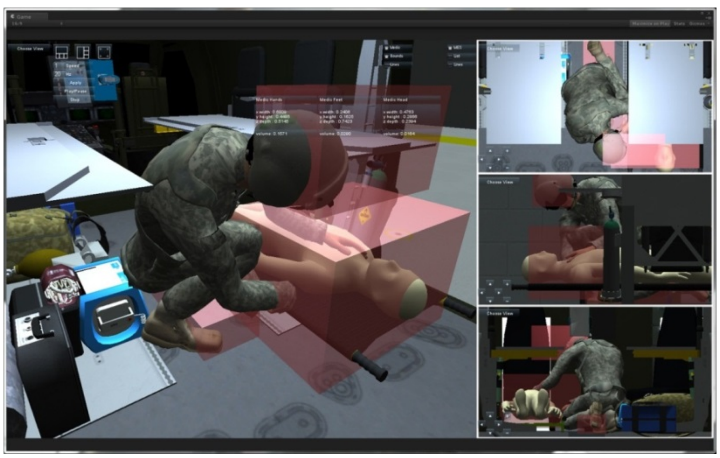


Figure 12. Envelope volume displayed within data processing application.

The TP's motion coordinates with respect to the center of the litter pan (expressed in *x*-, *y*-, and *z*-axis displacement recordings) were averaged for each scenario and each TP. The standard deviation (SD) for each average displacement value was calculated for each scenario and TP. Range of motion for each TP was calculated as the mean ±2SD, which gives 95 percent of adequate motion to accomplish the medical tasks.

Phase 2: Determining vertical litter spacing (Fort Rucker test: two participants)

During Phase 2 testing, required vertical litter separation was determined for all previously unsuccessful medical tasks identified during Phase 1.

Subjects

The same three experienced flight medic TPs used in Phase 1 (A, B, and C1) were eligible for participation in Phase 2. TP A and TP C1 completed this portion of testing; TP B was unavailable.

Equipment

In Phase 2, the HH-60 medical interior located at the U.S. Army School of Aviation Medicine (USASAM) Training Area 1 was used to simulate the IMMSS litter system. This interior allowed for incremental litter spacing changes so that the investigators could determine, in inches, the vertical space required to adequately complete each task.

As in Phase 1, the following equipment was available: air ambulance medical equipment set (MES) items (table 3); and GoPro® Hero3 cameras. Data acquisition was otherwise identical to Phase 1.

At the beginning of Phase 2 testing, each medical task was conducted with 24 in. of vertical separation while the TP was in full flight gear (i.e., Army Aircrew Combat Uniform [A2CU], Gentex® Head Gear Unit [HGU]-56 personnel [P] helmet, aviation-approved boots, and Air Warrior personal survival gear carrier). The TPs did not wear Nomex® gloves since they would not contribute positively or negatively to space utilization. This phase of testing was designed to validate the findings from Phase 1, which was performed with the TP wearing an Xsens suit with a head mounted tracker and without a helmet or Air Warrior personal survival gear carrier.

Vertical litter separation was measured from the bottom litter pan inboard edge center point to the upper litter pan bottom edge center point. A manikin (simulated patient) was placed on a standard NATO litter and the litter was secured in the lower right litter pan of the HH-60M medical interior simulator. The bottom edge of the lower litter pan was 3.75 in. above the aircraft floor. The study group lifted the upper litter pan to a vertical separation height of 24 in. from the lower litter pan. The TP attempted all medical tasks with a 24 in. separation except those listed in table 4. The study group noted unsuccessful tasks. Subsequently, all unsuccessful tasks were repeated at incrementally higher vertical litter separations until all tasks were either successfully completed, or the maximum allowable vertical separation of 37 in. was reached. Figure 13 shows the incremental vertical litter separation sequence starting from a separation of 24 in. between the litter pans and incrementally increasing the litter separation by 1 in. at a time.

Scenarios

TPs attempted all medical tasks except those listed in table 4. The clinical SMEs determined these tasks needed to be assessed for mitigation for the flight paramedic course, but should not be part of the data analysis.

Table 4.
Tasks removed from Phase 2 testing.

Task removed	Reason
24 - Use the SMEED™ for patient movement items	Requires 360 degree access to patient in the horizontal plane.
42 - Apply a traction splint	Requires more horizontal space than what is available in the IMMSS configuration.
43 - Apply a Reel Splint Immobilizer™ (traction splint)	Requires more horizontal space than what is available in the IMMSS configuration.

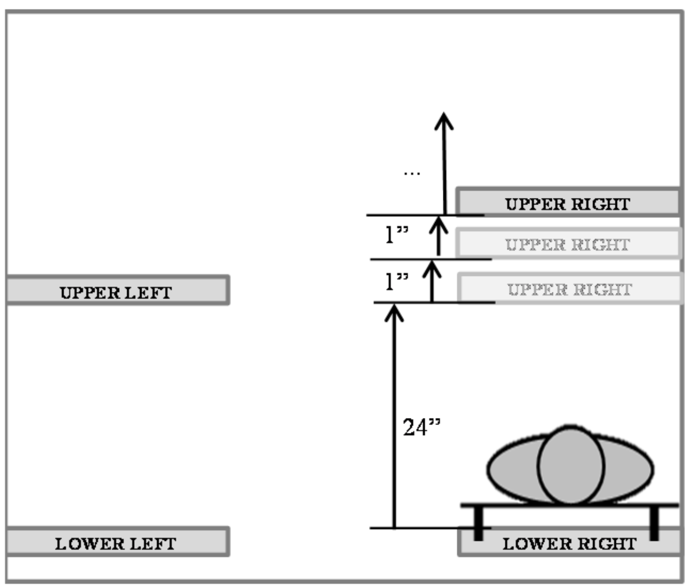


Figure 13. Phase 2 diagram, increasing height by 1 in. increments.

Additionally, TP A completed another set of medical tasks at decrements of 1 in., starting at 23 in. of vertical litter separation down to 14 in. of litter separation (shown in figure 14).

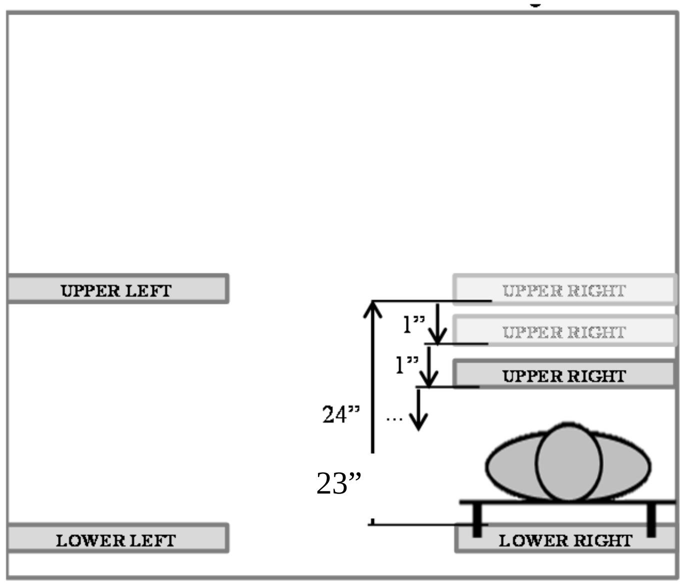


Figure 14. Phase 2 diagram, decreasing height by 1 in. decrements.

Phase 3: Determining vertical litter spacing (Fort Campbell test: 15 participants)

Subjects

To confirm the findings from Phase 2, 15 qualified flight medics or paramedics (n=15) at Fort Campbell, Kentucky with the 7th Battalion, 101st Aviation Regiment (C\7-101) general support aviation battalion (GSAB) with varying anthropometric dimensions were studied (table 5).

Equipment

An HH-60 aircraft from the C\7-101 GSAB was utilized. As in previous phases, the MES set was used; a single GoPro® Hero3 camera was used.

Scenarios

During testing, vertical litter separation was determined in a similar approach to phase 2. The study group positioned the upper litter pan at an initial vertical separation height of 18 in. from the lower litter pan (figure 15).

Table 5.
Anthropometric measurements of phase 3 TPs.

TP	Gender	Height (in.)	Percentile	Arm Span (in.)	Percentile	Weight (lb)	Percentile
1	M	72.25	90	72	55	158.6	28
2	M	74.5	98	77	95	274	>99
3	M	67.5	28	69	20	156.6	24
4	F	68	95	68	75	180	98
5	M	69	50	68.5	15	170	47
6	M	64	3	62	<1	187.4	73
7	M	75.5	>99	75	85	220	95
8	M	68.5	42	69.5	25	208.4	91
9	F	68	95	68	75	171.6	95
10	F	63.25	35	62	12	126.4	30
11	M	69.5	55	70	30	170.6	48
12	M	66.5	16	66.5	5	154.6	22
13	M	71	75	70.5	36	207.8	91
14	M	70	65	68.5	16	186.8	72
15	M	71	75	73.5	71	194	80

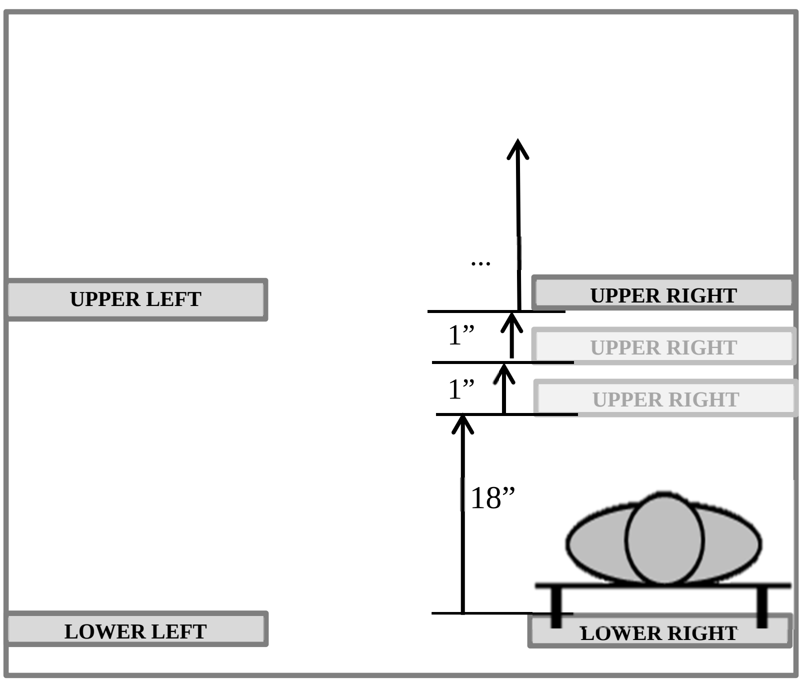


Figure 15. Phase 3-lower litter configuration (aft view).

The TPs attempted all medical tasks except those listed in table 4. In addition, a different MV was used during Phase 3. The MV was also a qualified and combat-experienced U.S. Army Aeromedical Physician's Assistant. This MV's interpretation of successful chest tube procedure completion (task 11) was different from the MV's interpretation during phases 1 and 2. For Phase 3, the chest tube procedure was not included in the tasks because the MV assessed that the TP would not be able to perform the actual procedure successfully on the outboard side of the patient at any vertical separation. After the conclusion of Phase 3 testing, the MVs concurred that the space required to perform task 11 would be similar to that required for the burn evaluation procedure (task 12). Both procedures required the TP to perform direct visualization of the injury as well as a hands-on evaluation.

As with prior phases, the MV noted all unsuccessful tasks. All unsuccessful tasks were repeated at incrementally higher vertical litter separations (by 1 in. at a time) until they were either successfully completed, or the maximum allowable vertical separation was reached (figure 15). Each TP was in full flight gear (i.e., A2CU, HGU-56P helmet, aviation approved boots, and Air Warrior personal survival gear carrier). The TPs did not use Nomex® gloves during this phase.

Another configuration was introduced during Phase 3 testing with the upper right litter pan positioned with 24 in. of vertical spacing from the ceiling. The stowed seats were removed from the ceiling. The study group placed the manikin and litter into the upper right litter pan as shown in figure 16. As with the previous configuration, each TP attempted all medical tasks except those in table 4. The MV noted all unsuccessful tasks, and the findings from this upper litter position were recorded for comparison to the findings of the lower litter position at a vertical separation of 24 in. from the upper pan.

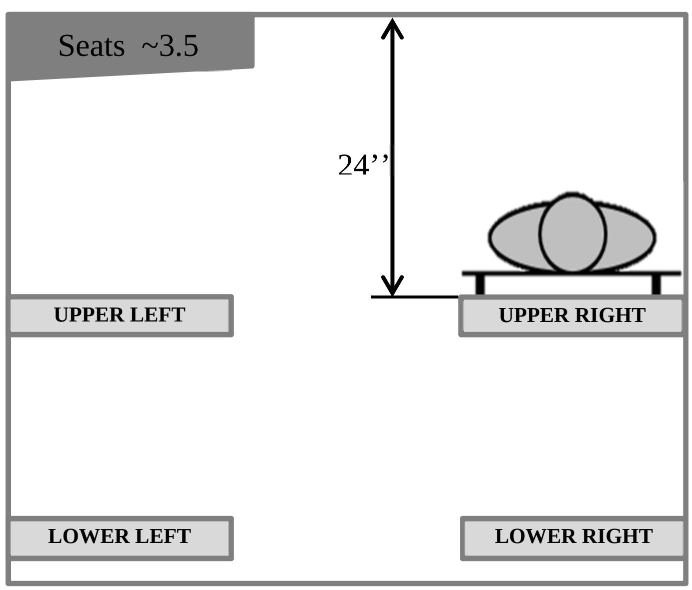


Figure 16. Phase 3-upper litter configuration (aft view).

Results

Phase 1

The MV tabulated and verified all successful and unsuccessful medical tasks (table 6).

The UH-60 "slick" scenario resulted in the highest success rate (96 percent) for all tasks among the TPs, while the UH-60 IMMSS with patient in upper/right position resulted in the lowest success rate (73 percent) for all tasks among the TPs.

The *x*-, *y*-, and *z*-axis displacements (i.e., TP's motion) were expressed with respect to center of active litter pan where treatment was applied (figure 17). Appendix C contains motion plots for all TPs and scenarios.

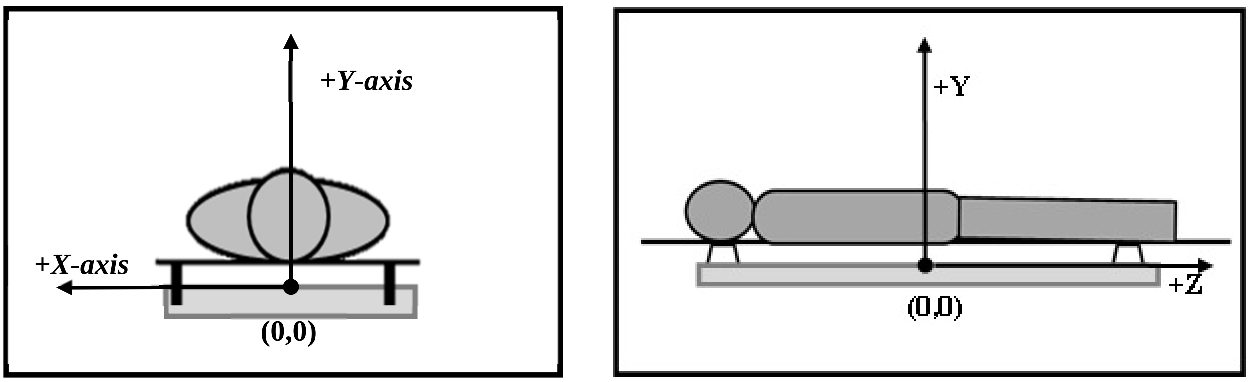


Figure 17. Coordinate system for the TP's motion.

Since scenarios 1 and 3 were conducted with the same configuration (treating a patient in the lower right litter pan the of UH-60 IMMSS), displacements for both scenarios were grouped to get a single average. Similarly, scenarios 2 and 8 were grouped, as were scenarios 5 and 6. Table 7 shows the mean and SD values of all body sensors for each displacement, scenario (or group of scenarios), and each TP. The TP's motion displacements for the unsuccessful medical tasks (table 6) were not included in the mean and SD calculations. Figures 18 through 20 show plots for the data given in table 7. In figure 18, the *x*-axis is the lateral distance from the centerline of the active litter pan. The bars are ±2 times the SD. In figure 19, the *y*-axis is the vertical distance above the active litter pan. The bars are ± 2 times the SD. In figure 20, the *z*-axis is the longitudinal distance from the middle line of the active litter pan. The bars are ± 2 times the SD.

<u>Table 6.</u>
Successful and unsuccessful medical tasks for each scenario and TP.

	UH-60 with slick floor			**UH-60 with IMMSS**											**HH–60 with medical interior**									
	Slick floor 54 in. vertical space (load position)			One patient 24.5 in. vertical space (lower/right)			Two patients 24.5 in. vertical space (lower/right)			Two patient 26.5 in. vertical space (upper/right)			Four Patients (upper/ right)	One patient 35 in. vertical space (upper/right)			Two patients 35 in. vertical space (upper/right)			Four patients 24 in. vertical space (middle/right)		
Task	2nd	75th	99th	2nd	80th	99th	2nd	80th	99th	2nd	80th	99th	99th	2nd	75th	99th	2nd	75th	99th	2nd	75th	99th
1	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	I	P
2	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
3	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
4	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
5	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
6	P	A	S	P	P	P	I	P	P	S	P	I	P	P	P	P	P	P	P	I	I	P
7	P	P	P	P	P	P	P	P	P	S	I	P	P	P	P	P	P	P	P	P	P	P
8	P	P	P	P	P	P	P	P	P	S	P	P	P	P	P	P	P	P	P	P	P	P
9	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
10	P	P	P	A	A	A	A	A	A	A	A	A	P	P	P	P	P	P	P	A	A	P
11	P	P	P	S	I	S	S	I	S	I	I	I	S	P	P	P	P	P	P	I	I	P
12	P	P	P	A	A	A	A	A	A	A	A	A	P	P	P	P	P	P	P	P	P	P
13	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
14	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
15	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
16	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
17	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
18	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
19	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
20	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
21	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
22	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
23	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
24	P	P	P	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
25	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
26	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
27	P	P	P	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
28	P	P	P	P	P	P	P	P	S	P	P	P	P	P	P	P	P	P	P	P	P	P
29	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
30	P	P	P	S	S	P	S	S	S	S	P	S	S	P	P	P	P	P	P	S	S	S
31	P	P	P	P	P	P	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
32	P	P	P	S	S	S	S	S	S	S	S	S	S	P	P	P	P	P	P	P	S	S
33	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
34	P	P	P	P	P	P	P	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
35	P	P	P	I	P	I	I	S	P	I	S	I	I	P	P	P	P	P	P	P	I	P
36	P	P	P	I	P	P	I	P	P	I	P	I	I	P	P	P	P	P	P	P	I	P
37	P	P	P	P	P	P	P	P	P	P	P	P	I	P	P	P	P	P	P	P	P	P
38	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
39	P	P	P	P	P	P	P	S	P	P	P	P	P	P	P	P	P	P	P	P	P	P
40	P	P	P	I	P	P	P	P	P	I	P	P	P	P	P	P	P	P	P	P	P	P
41	P	P	P	I	P	P	P	P	P	P	P	P	I	P	P	P	P	P	P	P	I	P
43	A	A	S	S	S	S	S	S	S	S	S	S	S	P	P	P	P	P	P	P	I	P
Pass rate	98%	95%	95%	71%	81%	81%	71%	74%	79%	67%	79%	74%	76%	95%	95%	95%	95%	95%	95%	86%	71%	90%

P	Task was completed as per CCFP standards.
S	Unsuccessful: Task could not be completed because of physical restrictions imposed by limited space.
A	Unsuccessful: Caregiver required assistance to complete this task.
I	Unsuccessful: Task completion resulted in an injury or a potential injury event incurred upon the patient or a potential injury event to the medic and/or untreated patient in an adjacent litter birth.

Table 7.
Mean and SD values for x-, y-, and z-axis displacements for all body sensors.

		X-axis			*Y*-axis			*Z*-axis		
	Medic percentile (height)	95% minimum (-2SD)	Average	95% maximum (+2SD)	95% minimum (-2SD)	Average	95% maximum (+2SD)	95% minimum (-2SD)	Average	95% maximum (+2SD)
UH-60 IMMSS Lower (SC 1 and 3) 26.5 in. vertical clearance	99^{th}	1.48	17.79	34.10	-4.63	19.23	43.10	-59.40	-16.10	27.20
	80^{th}	-0.78	16.42	33.62	-2.08	19.80	41.68	-47.79	-16.50	14.79
	2^{nd}	-8.10	12.43	32.96	-3.54	15.26	34.06	-63.84	-24.33	15.19
UH-60 IMMSS Upper (SC 2 and 8) 26 in. vertical clearance	99^{th}	-4.23	15.95	36.14	-27.84	2.58	33.00	-57.13	-18.95	19.24
	80^{th}	-7.47	12.78	33.04	-29.73	3.33	36.39	-59.08	-21.61	15.85
	2^{nd}	0.63	17.05	33.46	-29.46	2.19	33.84	-38.09	-12.67	12.75
UH-60 Slick (SC 4) 54 in. vertical clearance	99^{th}	6.36	24.43	42.51	-3.75	18.79	41.34	-32.67	-10.44	11.78
	80^{th}	9.38	26.33	43.29	-2.23	20.97	44.17	-32.16	-8.57	15.02
	2^{nd}	-5.20	17.44	40.07	-2.58	17.79	38.17	-25.09	-3.95	17.18
HH-60 Upper (SC 5 and 6) 35 in. vertical clearance	99^{th}	-4.43	15.99	36.40	-20.68	8.17	37.02	-51.33	-14.92	21.48
	80^{th}	-4.85	13.98	32.81	-21.68	10.18	42.05	-44.68	-14.72	15.25
	2^{nd}	-6.25	11.46	29.18	-20.70	7.32	35.34	-55.41	-19.24	16.94
HH-60 Lower (SC 7) 24 in. vertical clearance	99^{th}	2.74	18.72	34.70	-17.76	7.24	32.24	-54.71	-15.32	24.06
	80^{th}	2.00	18.73	35.46	-15.32	7.41	30.14	-46.15	-19.11	7.94
	2^{nd}	-5.56	15.96	37.47	-15.81	6.48	28.77	-48.25	-10.85	26.56

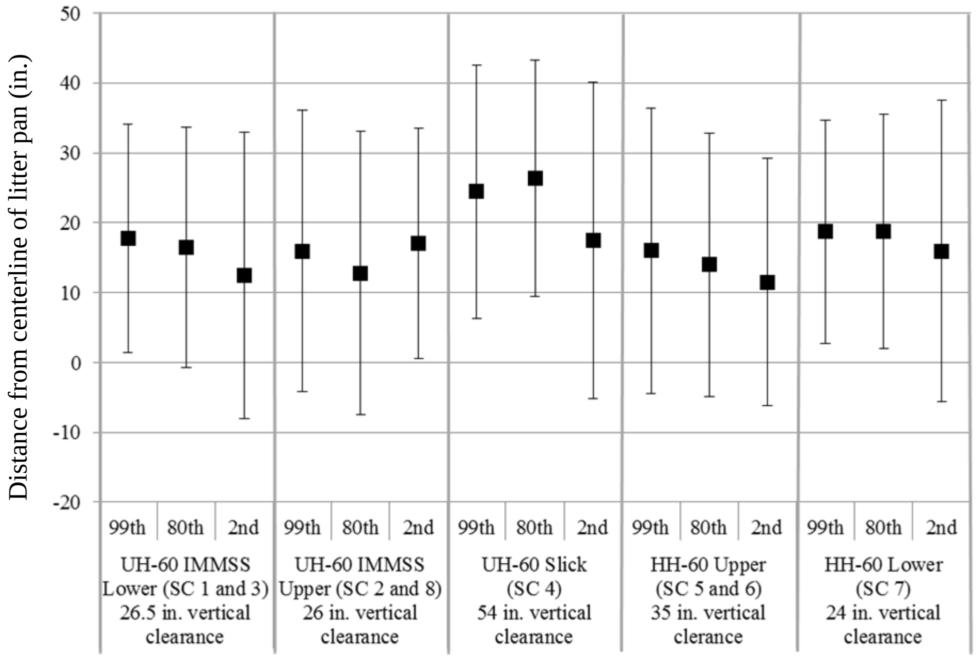


Figure 18. *X*-axis displacement for each TP (all body sensors).

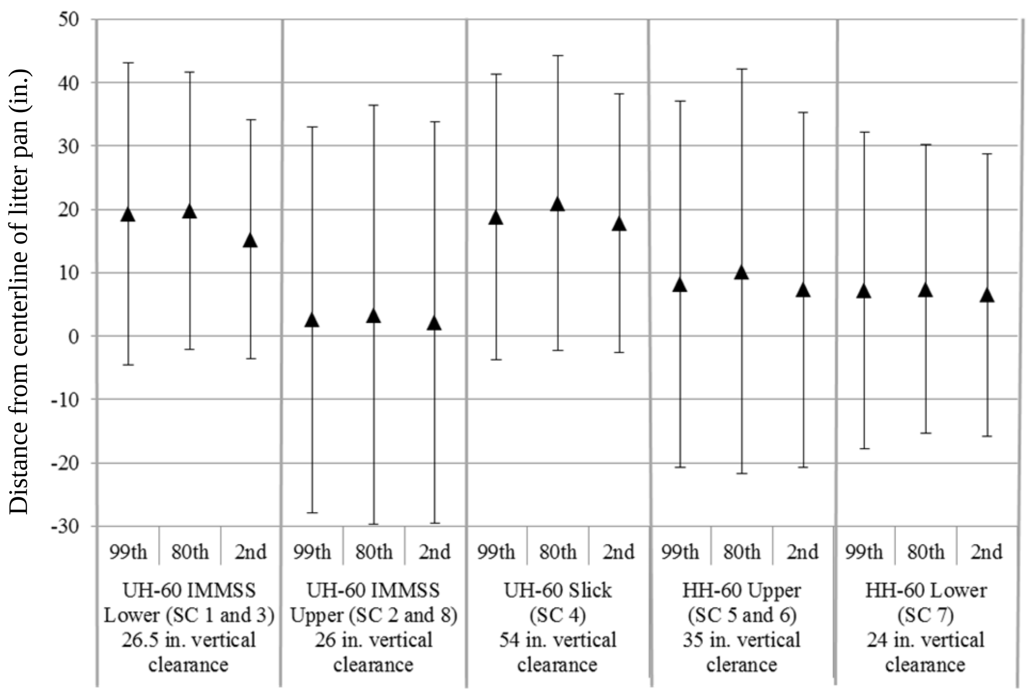


Figure 19. *Y*-axis displacement for each TP (all body sensors).

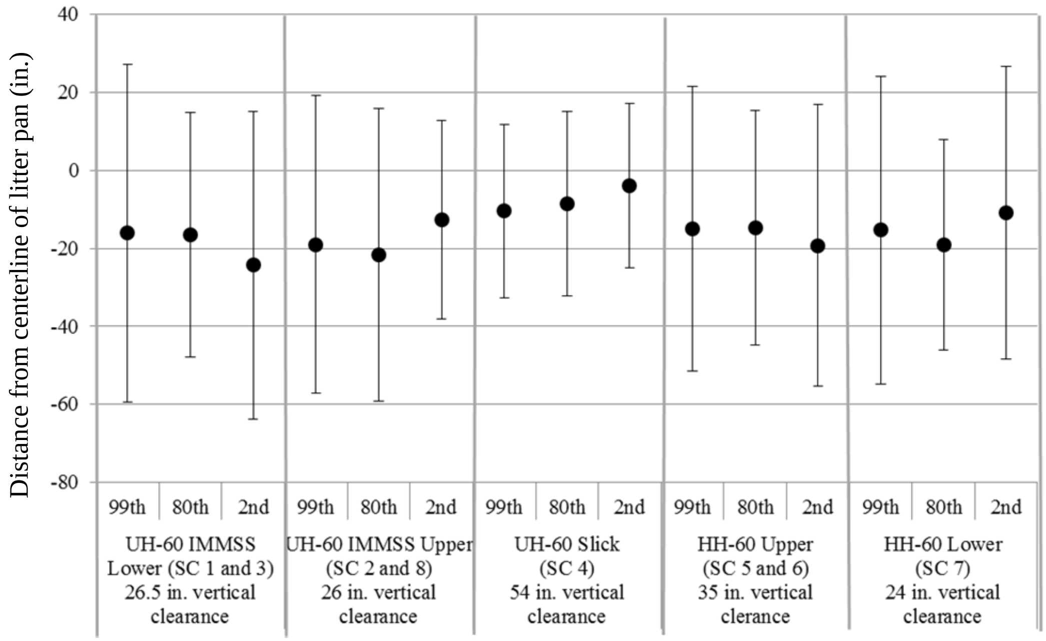
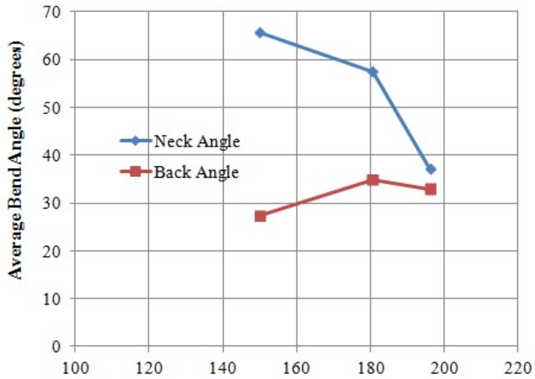


Figure 20. *Z*-axis displacement for each TP (all body sensors).

Figure 21 shows the TP's average neck and back bend angles for all scenarios as a function of the TP's height. Unsuccessful tasks were included in the bend angle calculations. For detailed neck and back bend angles for each scenario, refer to appendix D. Figure 21 displays the percent of time the TP's neck and back bend angles were above a 30 degree threshold. This threshold was based on the work of Buckle and Devereux (2002). Each TP completed the post-test questionnaires located in appendix E.



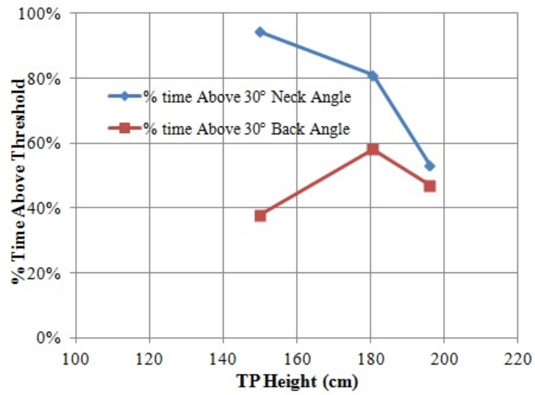


Figure 21. Average TP neck and back bend angles among all scenarios (top) and percent time spent at or above threshold of 30 degree bend angles (bottom) as a function of the TP's height.

The lateral and longitudinal spaces utilized in the UH-60 slick configuration, UH-60 IMMSS, and HH-60 medical interior during Phase 1 were 50 in. and 48 in., 44 in. and 94 in., and 43 in. and 82 in., respectively (figures 22-24).

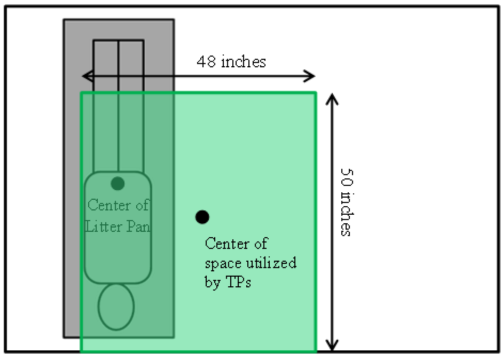


Figure 22. Lateral and longitudinal space utilized by all TPs in the UH-60 slick floor configuration.

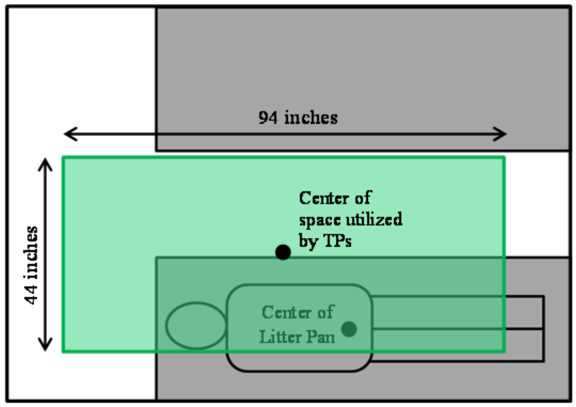


Figure 23. Lateral and longitudinal space utilized by all TPs in the UH-60 with IMMSS.

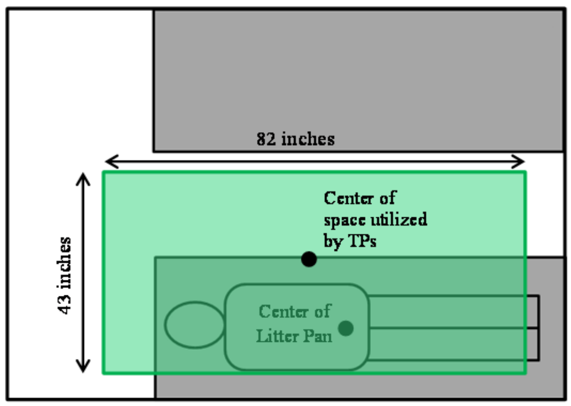


Figure 24. Lateral and longitudinal space utilized by all TPs in the HH-60 medical interior.

Phase 2

Tables 8 and 9 show the successful and unsuccessful medical tasks for TP A and TP C1 at various vertical litter separations while wearing full flight gear. Figure 25 shows completion rate of successful tasks as related to vertical litter space available for TP A and TP C1.

<u>Table 8.</u>
TP A phase 2 testing.

Inches of vertical spacing

	37	36	33	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14
Task 1	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	S	S
Task 2	P	P	P	P	P	P	P	P	P	P	P	S	S	S	S	S	S	S
Task 3	P	P	P	P	P	P	P	P	P	P	P	S	S	S	S	S	S	S
Task 4	P	P	P	P	P	P	P	P	P	P	P	P	P	S	S	S	S	S
Task 5	P	P	P	P	P	P	P	P	P	P	P	S	S	S	S	S	S	S
Task 6	P	P	P	P	P	P	P	P	P	P	P	S	S	S	S	S	S	S
Task 7	P	P	P	P	P	P	P	P	P	P	S	S	S	S	S	S	S	S
Task 8	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 9	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 10	P	P	P	P	P	I	S	S	S	S	S	S	S	S	S	S	S	S
Task 11	P	P	P	P	P	P	P	I	S	S	S	S	S	S	S	S	S	S
Task 12	P	P	P	P	P	I	S	S	S	S	S	S	S	S	S	S	S	S
Task 13	P	P	P	P	P	P	P	P	S	S	S	S	S	S	S	S	S	S
Task 14	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	S	S	S
Task 15	Not Assessed																	
Task 17	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	S
Task 18	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 19	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 20	Not Assessed																	
Task 21	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 22	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 23	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 24	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Task 25	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 26	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 27	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Task 28	P	P	P	P	P	P	P	P	P	P	P	P	P	P	S	S	S	S
Task 29	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 30	P	P	P	P	P	P	P	S	S	S	S	S	S	S	S	S	S	S
Task 31	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Task 32	P	P	P	P	P	S	S	S	S	S	S	S	S	S	S	S	S	S
Task 33	P	P	P	P	P	P	P	P	P	I	S	S	S	S	S	S	S	S
Task 34	P	P	P	P	P	P	P	P	P	I	S	S	S	S	S	S	S	S
Task 35	P	P	P	P	P	P	P	P	P	I	S	S	S	S	S	S	S	S
Task 36	P	P	P	P	P	P	P	P	P	P	P	P	I	S	S	S	S	S
Task 37	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	S	S	S
Task 38	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	S
Task 39	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	S	S
Task 40	P	P	P	P	P	P	P	P	P	P	P	P	S	S	S	S	S	S
Task 41	P	P	P	P	P	P	P	P	P	P	I	S	S	S	S	S	S	S
Task 43	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Pass Rate:	92%	92%	92%	92%	92%	85%	85%	79%	77%	69%	64%	54%	49%	46%	44%	38%	33%	28%

P	Task was completed as per CCFP standards.
S	Unsuccessful: Task could not be completed due to physical restrictions imposed by limited space.
A	Unsuccessful: Caregiver required assistance to complete this task.
I	Unsuccessful: Task completion resulted in an injury or a potential injury event incurred upon the patient or a potential injury event to the medic and/or untreated patient in an adjacent litter pan.

Table 9.
TP C1 phase 2 testing.

	Inches of Vertical Spacing between litter pans							
	37	36	33	28	27	26	25	24
Task 1: Load casualties into helicopter	P	P	P	P	P	P	P	P
Task 2: Open the airway	P	P	P	P	P	P	P	P
Task 3: Insert an oropharyngeal airway	P	P	P	P	P	P	P	P
Task 4: Insert a nasopharyngeal airway	P	P	P	P	P	P	P	P
Task 5: Insert a King LT	P	P	P	P	P	P	P	P
Task 6: Intubate a patient	P	P	P	P	P	P	P	I
Task 7: Perform a surgical cricothyroidotomy	P	P	P	P	P	P	P	I
Task 8: Perform endotracheal suctioning of a patient	P	P	P	P	P	P	P	P
Task 9: Perform a needle chest decompression	P	P	P	P	P	P	P	P
Task 10: Treat a casualty with a chest injury	P	P	P	P	P	P	I	I
Task 11: Insert a chest tube	P	P	P	P	P	P	P	I
Task 12: Administer initial treatment for burns	P	P	P	P	P	P	I	I
Task 13: Perform rescue breathing	P	P	P	P	P	P	P	I
Task 14: Ventilate a patient with bag-valve-mask system	P	P	P	P	P	P	P	P
Task 15: Set up a D-sized oxygen tank	Not Assessed							
Task 17: Administer oxygen	P	P	P	P	P	P	P	P
Task 18: Measure a patient's pulse oxygen saturation	P	P	P	P	P	P	P	P
Task 19: Measure a patient's blood pressure	P	P	P	P	P	P	P	P
Task 20: Operate the Propaq	Not Assessed							
Task 21: Operate the Zoll	P	P	P	P	P	P	P	P
Task 22: Operate the Alaris IV pump	P	P	P	P	P	P	P	P
Task 23: Operate the IV fluid warmer	P	P	P	P	P	P	P	P
Task 24: Use the SMEED for patient movement items	S	S	S	S	S	S	S	S
Task 25: Measure a patient's pulse	P	P	P	P	P	P	P	P
Task 26: Measure a patient's temperature	P	P	P	P	P	P	P	P
Task 27: Perform advanced cardiac life support	P	S	S	S	S	S	S	S
Task 28: Initiate treatment for hypovolemic shock	P	P	P	P	P	P	P	P
Task 29: Initiate an intravenous infusion	P	P	P	P	P	P	P	P
Task 30: Initiate a FAST 1	P	P	P	P	P	S	S	S
Task 31: Establish intraosseous infusion	P	P	P	P	P	P	P	P
Task 32: Apply a pressure dressing to an open wound	P	P	P	P	S	S	S	S
Task 33: Apply a hemostatic dressing (Axial)	P	P	P	P	P	P	I	S
Task 34: Provide basic emergency care for an amputation	P	P	P	P	P	P	P	I
Task 35: Apply a tourniquet to control bleeding	P	P	P	P	P	P	P	I
Task 36: Treat a casualty with an open abdominal wound	P	P	P	P	P	P	P	P
Task 37: Treat a casualty with an impalement	P	P	P	P	P	P	P	P
Task 38: Treat a casualty with an open head injury	P	P	P	P	P	P	P	I
Task 39: Apply a cervical collar	P	P	P	P	P	P	P	P
Task 40: Immobilize the pelvis	P	P	P	P	P	P	P	P
Task 41: Immobilize a fracture of the arm	P	P	P	P	P	P	I	I
Task 43: Apply a REEL splint	S	S	S	S	S	S	S	S
Pass Rate:	95%	92%	92%	92%	90%	87%	77%	59%

P	Task was completed as per CCFP standards.
S	Unsuccessful: Task could not be completed because of physical restrictions imposed by limited space.
A	Unsuccessful: Caregiver required assistance to complete this task.
I	Unsuccessful: Task completion resulted in an injury or a potential injury event incurred upon the patient or a potential injury event to the medic and/or untreated patient in an adjacent litter pan.

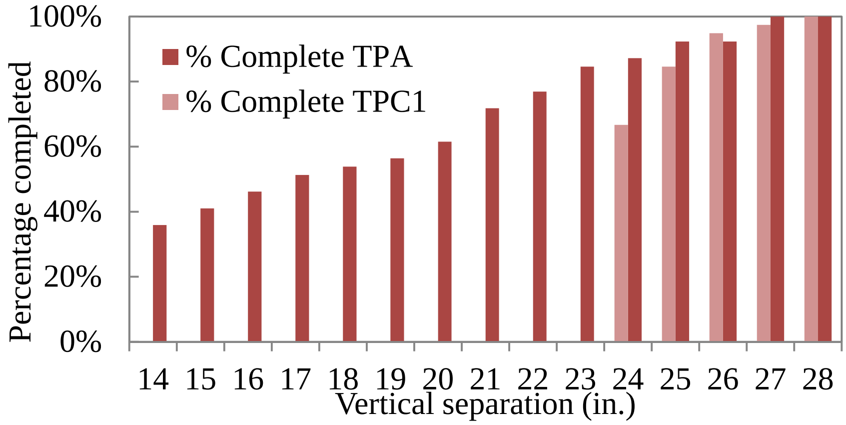


Figure 25. Completion rate as related to vertical separation of the litter pans.

Figures 23 through 25 illustrate TP A performing medical tasks at 26 in., 18 in., and 14 in., respectively, as examples of the increased challenge of reduced vertical litter spacing.

Figure 26. TP A can apply adequate pressure to femoral artery with 26 in. of available vertical space but cannot bandage while maintaining pressure (task 32).

Figure 27. TP A with 18 in. of vertical spacing cannot insert nasopharyngeal airway because of insufficient line of sight (task 4).

Figure 28. TP A working with 14 in. of available space.

Phase 3

Appendix F contains detailed results of each TP's tasks at all vertical litter separation heights, a comparison of 24 in. vertical separation with the simulated patient at the lower and upper position, and unsuccessful task plots as functions of the TP's height, arm span, and weight. Figure 29 shows the percentage of successful task completion for all TPs. Based on the findings from phases 1 and 2, the study team decided to attempt the cardiopulmonary resuscitation (CPR) procedure (task 27) at a vertical litter separation of 37 in. only, which resulted in 4 out of 15 TPs successfully completing CPR at that height.

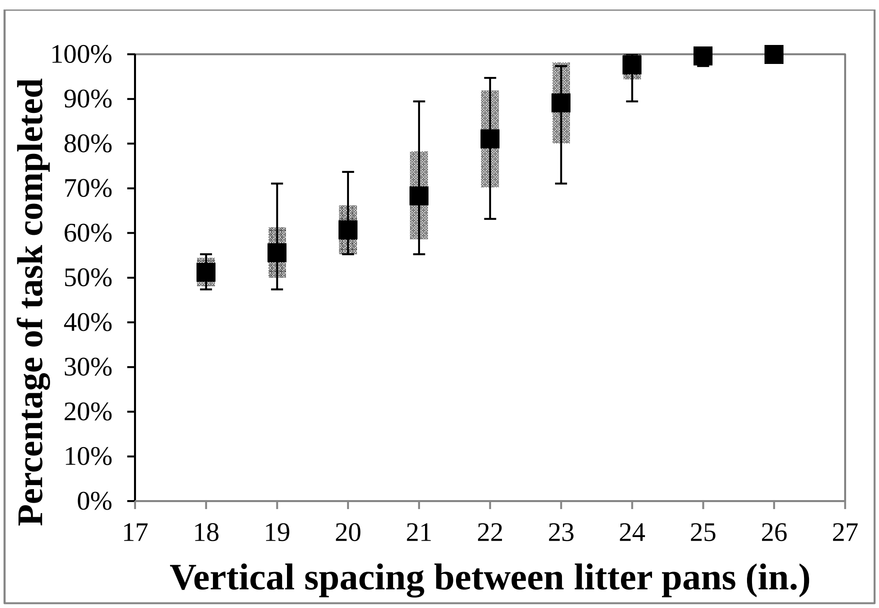


Figure 29. Average percentage of tasks completed successfully, excluding task 27 (CPR), among all TPs (squares), standard deviation (rectangles), and data range (bars).

Table 10 shows the number of unsuccessful medical tasks with 24 in. of vertical spacing available in the upper and lower litter pan positions. In the upper litter pan position, the litter pan was 29 in. above the aircraft floor, and in the lower litter pan position, the litter pan was only 3.75 in. above the aircraft floor. Figures 27 and 28 show the number of additional unsuccessful tasks in the upper litter position compared to the lower litter position as a function of the TP's height and arm span, respectively. Table F-1 in appendix F shows which tasks were failed in the upper and lower positions.

Table 10.
Comparison of 24 in. of vertical spacing in upper and lower litter positions.

TP number	TP height (in.)	TP arm span (in.)	TP weight (lb)	Number of unsuccessful tasks		Difference
				24 in. lower position	24 in. upper position	
1	72.25	72	158.6	0	2	2
2	74.5	77	274	4	6	2
3	67.5	69	156.6	0	4	4
4	68	68	180	0	6	6
5	69	68.5	170	3	8	5
6	64	62	187.4	1	7	6
7	75.5	75	220	1	5	4
8	68.5	69.5	208.4	2	3	1
9	68	68	171.6	1	7	6
10	63.25	62	126.4	0	2	2
11	69.5	70	170.6	0	2	2
12	66.5	66.5	154.6	0	3	3
13	71	70.5	207.8	0	2	2
14	70	68.5	186.8	0	3	3
15	71	73.5	194	1	2	1

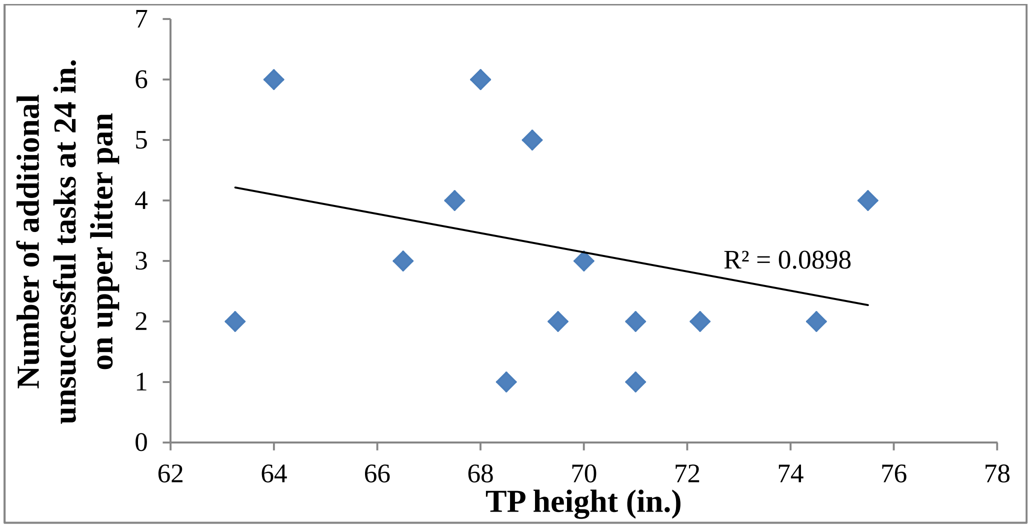


Figure 30. Number of additional unsuccessful tasks in upper litter pan position as a function of TP height.

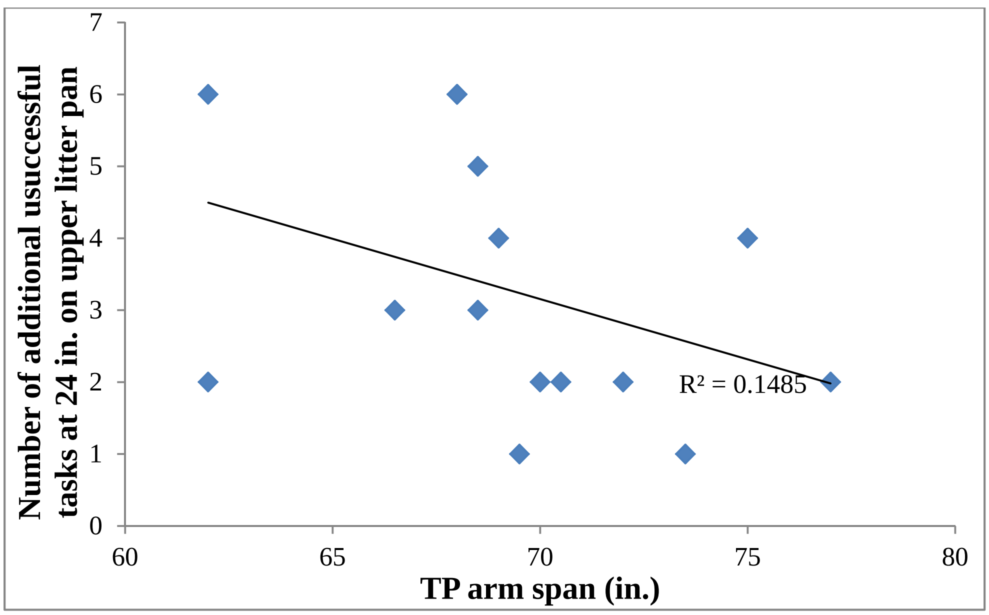


Figure 31. Number of additional unsuccessful tasks in upper litter pan position as a function of TP arm span.

Discussion

Enroute care in the U.S. Army has evolved over time from casualty evacuation to dedicated medical evacuation with highly trained flight paramedics equipped with state-of-the-art medical technology. The 2012 DOD Directive 5100.01 defines aeromedical intratheater evacuation as a core function of the U.S. Army. This continuing evolution prompted the MEDEVAC Enterprise to endorse the E2C2 study (DOD, 2010).

Critical medical task performance in UH- and HH-60

The study identified limitations in the current UH- and HH-60 medical interiors for rendering critical life-saving medical tasks. The mean success rate for medics attempting the medical tasks in the UH-60 IMMSS was 75 percent, compared to 91 percent with the HH-60M medical interior. The data suggest the medical tasks were unsuccessful because of aircraft interior structural physical limitations, primarily vertical clearance. As expected, the relatively unobstructed and expansive UH-60 slick configuration enabled an average 96 percent success rate among the TPs.

The tasks included in the present study were judged to be space-consuming with high probability of impacting patient morbidity and mortality, if not performed adequately. Examples of degraded tasks include: intubating a patient, inserting a chest tube, administering initial treatment for burns, applying a pressure dressing to an open wound, and treating a casualty with an impalement and open abdominal wound. Any delay or inability to complete these critical tasks could adversely affect patient outcome and survival.

Each unsuccessful medical task implies an increased risk of morbidity and mortality. In some cases, we observed TPs improvising ways to complete medical tasks despite the limited available space. However, completing a task in a nonstandardized or improvised manner, using a method that does not adhere to a established clinical practice guideline (CPG), could cause further injury to the patient and/or provider, still posing a significant risk of morbidity and mortality.

Vertical space limitations caused a majority of the unsuccessful medical tasks. However, task number 43 (apply a Reel Splint Immobilizer™ in the slick UH-60 and IMMSS configurations) and task number 6 (intubate a patient in the slick UH-60 configuration) were unsuccessful because of longitudinal physical space restrictions. The SMEED™ task required the TP to assess patient injuries from all sides (i.e., 360 degree patient access), which was only available in the UH-60 slick configuration. The CCFP's patient care duties are physically intense and demanding even under the best of circumstances, but space-limiting environments exacerbate these difficulties.

As space is reduced, tasks become more physically demanding, accelerating the onset of caregiver fatigue and increasing the likelihood of negative patient care events. This was supported by the TPs' after action surveys, indicating some of the tasks may have caused muscle

fatigue throughout the scenarios. Certainly, muscle fatigue could have played a part in unsuccessful task completion in cases where further potential injury was incurred by the patient, TP, or adjacent patient, denoted by an “I” in tables 6, 8, and 9. However, physical fatigue did not influence medical tasks that were unsuccessful because of physical restrictions imposed by limited space (denoted by an “S” in tables 6, 8, and 9).

A detailed analysis of the impact of reduced medical task performance in the current UH- and HH-60 litter configurations is in preparation and will be published separately. However, note that the complete results of this testing are contained in the present report (tables 6, 8, and 9; appendix F).

Vertical litter spacing in MEDEVAC helicopters

Recommending a “minimum” vertical clearance between litter pans for medics to adequately complete critical care tasks requires consideration of several factors: patient vertical location, patient anthropometry (e.g., abdominal and thoracic anterior-posterior depth), provider anthropometry, military/flight gear worn by patients or providers, litter thickness, the specific medical tasks to be performed, as well as operational factors such as aircraft vibration, night operation, and hoist operation. This study examined only some of these factors and must be followed with systematic research studies. Nonetheless, this study made significant progress toward reliable recommendations for future MEDEVAC helicopter acquisition programs.

It is important to note that the present study did not address “optimum” clearances in any generalizable way. Rather, the study identified “adequate” space to perform a set of medical tasks in specific existing medical interiors, namely the UH-60 IMMSS configuration and HH-60 medical interior. The study did identify improvements for litter vertical separation by determining the space required to adequately complete the medical tasks across a larger number of subjects (n=15) and wider range of anthropometric dimensions than the 1986 USAARL study. In future studies, “optimum litter clearances” should be defined more accurately and should consider medic posture and user feedback.

Although the UH-60 Technical Manual specifies a minimum vertical separation of 18 in. between litter pans, this has previously been shown to be inadequate for enroute care (Mitchell & Wells, 1986). During Phase 2 of our study, TP A had a completion rate of only 46 percent with 18 in. of vertical litter separation, supporting the findings of Mitchell and Wells. Phase 1 was performed with a minimum of 24.5 in. of vertical spacing (or 11 in. above the patient) for UH-60 IMMSS configurations, ranging up to a maximum of 54 in. of available vertical spacing (or 40.5 in. above the patient) for the UH-60 slick configuration.

Mitchell and Wells (1986) determined the minimum required vertical and lateral separation of litters to be 20 and 21 in., respectively. However, the study included only one medic with a 47th percentile height (Gordon, et al., 1989) performing medical tasks starting from two fixed litter positions while varying the vertical clearance. The 1986 data should be considered to represent the minimum space required for a medic of average stature to render a basic level of enroute

care, realizing that medical personnel of larger or smaller dimensions were not considered and may not be able to function satisfactorily.

For the purposes of this study, the combined thickness of the litter and manikin was 13.5 in. The manikin's chest thickness is 10 in., equivalent to a 70th percentile male (Gordon et al., 1989). A patient's thickness can certainly vary, not only for the seminude, but clothed as well (appendix G). It should be noted that a 10 in. chest thickness reflects a 50th percentile male in accordance with a more recent study (appendix F). In most cases, the medic cuts through fabric to assess potential injuries, but a casualty's gear should also be considered during litter-support system design.

In Phase 1, scenarios 5 and 6, the vertical litter pan spacing of 35 in. (or 21.5 in. above the patient) allowed the TPs to complete all medical tasks except for the CPR and SMEED™ tasks. Unsuccessful completion of the medical tasks was consistent at the 24.5 in. vertical space between litter pans, regardless of TP height, patient location, or platform type. Consequently, between 24.5 to 35 in. unobstructed vertical litter pan separation (or 11.0 to 20.5 in. unobstructed above the patient) was needed for all medical tasks to be completed successfully (with the exception of SMEED™ and CPR tasks). The TP did not wear a helmet during phase 1 since we could not attach the head motion capture sensor to the helmet. While the sensor added some thickness, it is not the same as a helmet.

During Phase 2, the minimal adequate vertical clearance was determined for unsuccessful tasks from Phase 1 with the TP wearing full flight gear, including a helmet. The TP did not wear the Xsens suit, so the motion capture was not recorded; however, a GoPro® video camera recorded the events. Unfortunately, TP B was not able to participate in Phase 2 testing.

TP C1 (80th percentile male) and TP A (99th percentile male) were able to complete all medical tasks at a vertical litter spacing of 28 in. except task 24 (SMEED™), task 27 (CPR), and task 43 (apply Reel Splint Immobilizer).™ Tasks 24 and 43 were not completed because horizontal spacing was inadequate. At a vertical litter spacing of 36 in., TP C1's arms could not be fully extended and elbows could not be locked, causing a failure to complete task 27 (CPR). However, with an extra inch of vertical clearance, TP C1 was able to complete the task (figures 29 and 30). In contrast, TP A was unable to complete the CPR task at the 37 in. vertical litter spacing because of height and arm span limitations. TP C1 had an arm span at the 50th percentile, suggesting arm span plays a critical role in identifying negative patient care events and should be considered in future studies.

Figure 32. TP C1 unable to fully extend arms and lock elbows while attempting to perform task 27 with 36 in. of vertical space.

Figure 33. TP C1 able to fully extend arms and lock elbows to successfully complete task 27 with 37 in. of vertical space.

Test results from Phase 3 revealed a successful completion rate of 97.4 percent among 15 TPs with a vertical litter separation of 25 in. Only two TPs (95th percentile female and 98th percentile male) had an unsuccessful medical task at the 25 in. vertical litter separation, with the simulated patient in the lower litter position. At the 26 in. vertical separation, all TPs successfully completed the medical tasks. These findings were recorded at 2 in. lower than the Phase 2 findings. One possible explanation for this variability may have been the different MVs used for Phases 2 and 3, resulting in a possibility of subjective variation in assessing the success of a medical task.

The litter at an upper position (24 in. below the ceiling) resulted in more unsuccessful medical tasks compared to the lower position with the same vertical clearance (appendix F), corroborating the findings of Mitchell and Wells (1986). Although there was a slight downward trend in the difference between unsuccessful tasks in the upper and lower litters (table 10) with increasing TP height and arm span (figures 27 and 28), the correlation coefficient was small. These findings suggest that a TP requires more vertical space to treat a patient in an upper litter pan compared to the lower litter pan. Figures 31 and 32 show TP 2 successfully completing a task in the lower litter position with 24 in. of vertical clearance. TP2 unsuccessfully attempted the same task in the upper position with the same amount of vertical clearance. There are many factors that affected the difference in success rates at varying litter pan heights, including ergonomic factors such as medic stance and stability and the medic’s ability to maneuver into challenging work angles. The light bar may have also added additional space constraints in rendering care with the patient in the upper litter pan location (figure 35).

Figure 34. TP 2 able to complete task 37 with 24 in. vertical clearance in the lower litter position during Phase 3.

Figure 35. TP 2 unable to complete task 37 with 24 in. vertical clearance in the upper litter position during Phase 3.

An unrecorded factor that may have played a role on the outcome of this study was the TPs' medical experience. Although the TPs were validated to meet CCRP standards, the range of skill level and ability to work in tight spaces may have also played a role in the outcome of this study. Confidence and ability to effectively utilize the available space could affect the perception of space required for a given task--although the medic may be physically able to complete the tasks, if they are outside of their comfort zone and their confidence level is decreased, the medic may have a predisposition for task failure. Figure 36 shows a task that requires the TP to determine if he is applying enough pressure, as the MV could not visually tell how much pressure was being applied. Less experienced or confident medics might have a different opinion on how much pressure is enough, which would result in them requiring more vertical clearance than a more experienced medic.

Figure 36. TP 15 required 25 in. of vertical space to complete task 32.

Motion data and task analysis

The motion data for task 1, loading the patient into the aircraft, was not considered in the analysis since no medical care is given during loading. Loading the patient in the aircraft was selected as a task because it marks the starting point of patient care aboard the helicopter. Video recordings are available for further analysis, if needed. Bruckart and Licina (1994) found it would take between 230 to 268 s to load six patients into the UH-60Q. Kinsler and Barazanji (2011) found it would take an average of 213 s to load three patients into a fixed-position litter system, as compared to an average of 155 s using the moving litter lift system in the base medical interior of an HH-60M MEDEVAC helicopter.

The *y*-axis vertical displacement shown in figure 18 represents the mean + 2*SD of all 32 body sensors, which overestimate the vertical displacement because of a high SD. A better measure for the vertical displacement was to use only the head sensor data (mean + 2*SD), which has lower variability. For the lateral and longitudinal displacements, the motion data from all the body sensors are more desirable and found to be in agreement with the graphical plots in appendix C. In the UH-60 slick configuration, the TPs used up to 48 in. of vertical spacing (measured to aircraft floor) or about 34.5 in. above the patient to complete the medical tasks. This finding was obtained from the largest mean + 2*SD of head sensors' vertical displacement for the UH-60 slick. For the UH-60 IMMSS and HH-60 scenarios, the TP used the entire vertical clearance available based on the head sensor motion data and GoPro® video recordings. It should be noted that head motion plots for the *x-/y-* and *z-/x-axis* directions do not necessarily represent head motion directly above the patient, but often are adjacent and above the upper litter pan if the treated patient is in the lower position. For example, after watching the GoPro® videos, the study team noticed the 99th percentile TP used as much vertical space while kneeling down and performing the medical tasks on a patient in the lower litter position of the IMMSS as he did when standing. His head was in the aisle and at a higher position than the upper litter pan most of the time since he had a long arm span, but with two dimensional representations in the *x-/y-* and *z-/x-axis* graphs it looks as though his head is going through the upper litter pan. However, looking at the *z-/x-axis* graph, it is noticeable that all three medics were predominantly in the aisle of the helicopter or at the aft end of the litter pan when performing the tasks (appendix C). Therefore, motion data should be reviewed carefully, and watching the video recordings should help clarify the motion data.

To address human factors issues, neck and back bend angles were calculated and averaged for all scenarios and each TP. According to *Work-Related Neck and Upper Limb Musculoskeletal Disorders* by Buckle and Devereux (2002), at a 30 degree flexion, it took 300 minutes. for severe pain to be reported. At a 60 degree flexion, the corresponding time was 120 minutes. For our study, 30 degrees of flexion was used as the threshold (figure 21).

The TP's neck angle increased with shorter stature (up to 66 degrees for a height of 4 ft,11 in. versus 37 degrees for 6 ft, 5 in.). This trend remained regardless of platform type. Back angle was less correlated with stature. Figure 21 shows that the 2nd percentile TP's neck angle was above 30 degrees of flexion 94 percent of the time during all tasks and scenarios. Surprisingly,

the 99th percentile TP's neck angle was much lower (by 28 degrees) and back angle was slightly higher than the 2nd percentile TP, suggesting complex postures were assumed during this study for the TPs to accomplish their tasks. These findings support the need to further investigate the ergonomic role of postures (such as squatting, kneeling, slouching, hunching, etc.) by flight medics and paramedics in the medical interior design.

Limitations

Schedules and resources caused limitations in this study. Only three TPs were selected for Phase 1, which was insufficient to allow statistical comparisons of range of motion and height. The inter-participant motion variance was expected to be small because of the wide range of selected TPs' height and arm reach, as well as the TPs' experience and skills, which represented a typical sample of U.S. Army flight medics. Intra-participant variance of motion for each scenario could not be assessed since only one run was conducted for each TP as a result of schedule conflicts and restricted resources. However, since these TPs were all experienced medics and validated by the MV, it is probable that the range of motion would have varied only slightly if the TP was able to complete more than one run.

Positional drift was a normal occurrence with the Xsens system. This drift, when associated with multiple sensors over the body of the TP, produced several inches of distance variations when translated to the data output. The technical team overcame this limitation by matching actual motion data to the 3D image for each appendage. This reduced the drift and aligned the motion of the TP character appendage on the 3D video to the actual movement of the TP as captured by the cameras. While this procedure corrected the drift error, it was time-consuming and caused the production of the 3D video to take much longer than if the MVN MotionGrid system, which allows for drift-less data capture, had been used with the aircraft. Unfortunately, the MVN MotionGrid failed to work correctly during prestudy testing, since the system could not accurately pick up motion sensors that are behind a metal structure, such as the aircraft skin. The resultant use of alternate production methods required i3D development to take approximately 2 to 3 days longer than expected per scenario, resulting in an additional 30 to 45 days needed for data processing.

This study did not include special mission equipment (e.g., night vision goggles, hoists), or specialized medical equipment (e.g., incubators, patient isolation systems). This study should be considered as a baseline; follow-on test plans should include special mission equipment.

The sensitivity of the MVN MotionGrid system calibration to metal caused the study team to utilize multiple GoPro® Hero3 video cameras to establish reference points for the i3D team. This system generated the applicable reference points, but was a limitation because the cameras could not be positioned properly in the aircraft to capture all angles and TP movements as they conducted the medical tasks.

Conclusions

This study supports the team's short-term objectives to identify factors causing enroute critical life-saving medical task failures and to produce insights into structural physical aircraft interior limitations. The study supports long-term objectives to address P3I of current UH-60 and HH-60M aircraft medical interiors and kits, contribute to design enhancements for future U.S. Army MEDEVAC aircraft medical interiors (eliminating current physical limitations to the enroute critical care management of wounded Soldiers), and prevent structural and physical limitations in U.S. Army next-generation vertical lift aircraft.

Across multiple UH-60 and HH-60M patient configurations, the TPs, all qualified Army flight medics or paramedics, were unable to complete several key medical tasks. While most tasks could be completed successfully, vertical litter spacing was identified as a frequent impediment to effective inflight critical care. Further analysis of these medical tasks and their impact on patient care is underway and will be reported separately.

Note that if the manual CPR task requirement was replaced with a materiel solution (such as an automated CPR machine), the E2C2 study findings suggest that a minimum vertical litter spacing of 26 in., with a patient in the lower litter position at about 3 in. above floor, would provide the CCFP with the vertical spacing to adequately conduct all required medical tasks, except the ability to apply a Reel Splint Immobilizer™ or manipulate the SMEED.™

There are other important limitations that should be considered: a) the subjective nature of the medical validators' assessments of provider performance; b) more vertical space is required to treat a patient with a 95th percentile chest depth, or 11.04 in., compared to the 70th percentile chest depth, or 10 in. manikin used in this study (appendix G); and c) the real-world dynamic operational MEDEVAC environment involves additional factors (e.g., vibration, motion, temperature) that could affect the space required to provide effective inflight medical care. Given those study limitations, two recommendations can be made regarding possible improvements to the IMMSS: First, a litter vertical clearance of at least 28 in. is recommended. Second, more urgent patients should be positioned in the lower litter pan, and less urgent patients should be loaded into the upper litter pan.

It is critically important that, in the near future, the U.S. Army determine the requirements for helicopter medical interior design. The limitations reported by users in the field, and study results like those reported here, indicate the need for rigorous empirical research to assist with current MEDEVAC aircraft fleet interior improvement, as well as to identify accurate space requirements for enroute care into the future--such as the Future Vertical Lift program. These studies should occur early to avoid costly retrofits. A cost-effective strategy would entail the construction of a configurable medical interior simulator at USAARL, facilitating a broad range of important enroute care studies.

Such a robust research program would provide empirical data to answer a range of important questions:

- How much space is necessary (and optimum) between litters, horizontally and laterally, to complete the critical medical tasks?

- How many litters are optimum, based on mission data from operations and typical number of casualties carried?

- What modular capabilities provide the optimum dimensions and spacing for MEDEVAC interiors?

- What cabin dimensions (vertical, lateral and longitudinal) allow for flight medics and critical care nurses to successfully perform medical tasks while in flight?

- What range of distance (optimum) from the flight paramedic should equipment be stationed to allow for access without moving from a patient treatment position?

- What implications are presented by special mission equipment for space and configuration models of current and future cabins for MEDEVAC aircraft (e.g., night vision goggles, hoist operations, special medical gear)?

- What are the human factor implications, short- and long term, for medical provider bend points of the neck, back, and legs at large angles? What countermeasures will be effective?

- What are the space requirements for patient care in ground MEDEVAC vehicles?

References

Alejo, J.S., Martin, M.G., Ortega-Mier, M., and Garcia-Sanchez, A. 2009. Mixed integer programming model for optimizing the layout of an ICU vehicle. BioMed Central. 9: 224.

American Society for Testing and Materials (ASTM). 2003. Standard specification for rotary wing basic life support, advanced life support, and specialized medical support air ambulances. West Conshohocken, PA: Committee F30. WK 1254 (formerly ASTM F 1119– 91, F 1124-91, and F 1146-91) F3000000203001.

Anderson, P.B. 2012. Strategic plan for Product Director MEDEVAC. (unpublished staff study) Version ii.

Bruckart, J.E., and Licina, J.R. 1994. Technical evaluation of the UH-60Q: Litter lift and seating plan. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL report number 94-7.

Buckle, P., Devereux, J. 2002. The nature of work-related neck and upper limb musculoskeletal disorders. Applied Ergonomics. 33(3): 207-17.

Chaffin, D.B. 1973. Localized muscle fatigue – definition and measurement. Journal of Occupational Medicine. 15(4): 346-54.

Department of Defense. 2002. TM-1-1520-237-10 (change 10) technical manual: operator's manual for UH-60A, UH-60L, and EH-60A helicopters (30 Sept 2002). Washington, D.C. TM 1-1520-237-10.

Department of Defense. 2010. Function of the Department of Defense and its major components. Washington, D.C. Directive Number 5100.01.

Department of the Army. 2009a. Technical manual operator's manual for helicopters, utility tactical transport UH-60M NSN 1520-01-492-6324 (EIC: RSP) HH-60M NSN 1520-01-515-4615 (EIC: RSQ) TM 1-1520-280-10. Washington, D.C. TM 1-1520-280-10 (change 5).

Department of the Army. 2009b. Technical manual operator's manual for UH-60A, UH-60L, EH-60-A helicopter. Washington, D.C. TM 1-1520-237-10 (change 4).

Department of the Army. 2013a. Procedures for awarding additional skill identifier (ASI) "F2", nationally registered flight paramedic. Washington, D.C. Milper Message Number 13-069, Proponent AHRC-EPA-A.

Department of the Army. 2013b. Soldier's manual and trainer's guide, MOS 68W, health care specialist skill levels 1, 2 and 3. Washington, D.C. STP No. 8-68W13-SM-TG.

Golob, R., and Sykes, M. 2002. Workplace guidelines for the prevention of musculoskeletal injuries: a joint initiative. Victoria, British Columbia: B.C. Government and Service Employees' Union & British Columbia Public Service Employee Relations Commission.

Gordon, C.C., Churchill, T., Clauser, C.E., Bradtmiller, B., McConville, J.T., Tevvetts, I., and Walker, R.A. 1989. 1988 Anthropometric survey of U.S. Army personnel: methods and summary statistics. Natick, MA. U.S. Army Natick Research, Development and Engineering Center. Technical Report Natick/TR-89/044.

Guo, H-R. 2002. Working hours spent on repeated activities and prevalence of back pain. Occupational and Environmental Medicine. 59: 680-688.

Kinsler, R., and Barazanji, K. 2011. Assessment of fixed position litter loading in the HH-60M MEDEVAC helicopter. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Technical Memorandum 2011-19.

Lester, J.D., Hsu, S., and Ahmed, C.C. 2012. Occupation hazards facing orthopedic surgeons. American Journal of Orthopedics. 41(3): 132-9.

Mitchell, G. W., and Wells, A. S. 1986. Determination of space requirements for medical tasks on MEDEVAC aircraft. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL LR-86-7-3-3.

North Atlantic Treaty Organization. 1999. Standardization agreement: Aeromedical evacuation. Brussels, Belgium. STANAG 3204 AMD (edition 6).

Appendix A.

Medical interior figures with dimensions – phase 1.

This page intentionally left blank.

Appendix A.

Medical interior figures with dimensions – phase 1.

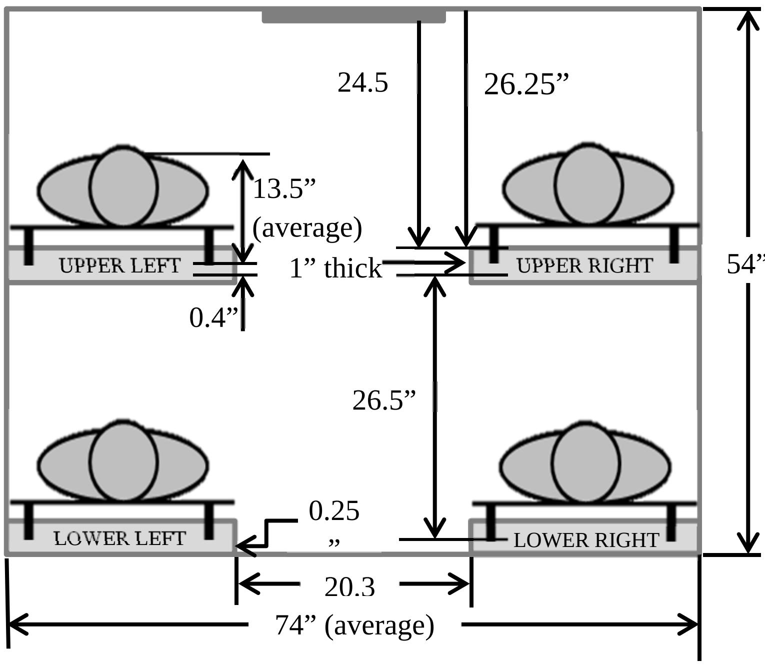


Figure A-1. Aft view – UH-60 with IMMSS – full dimensions.

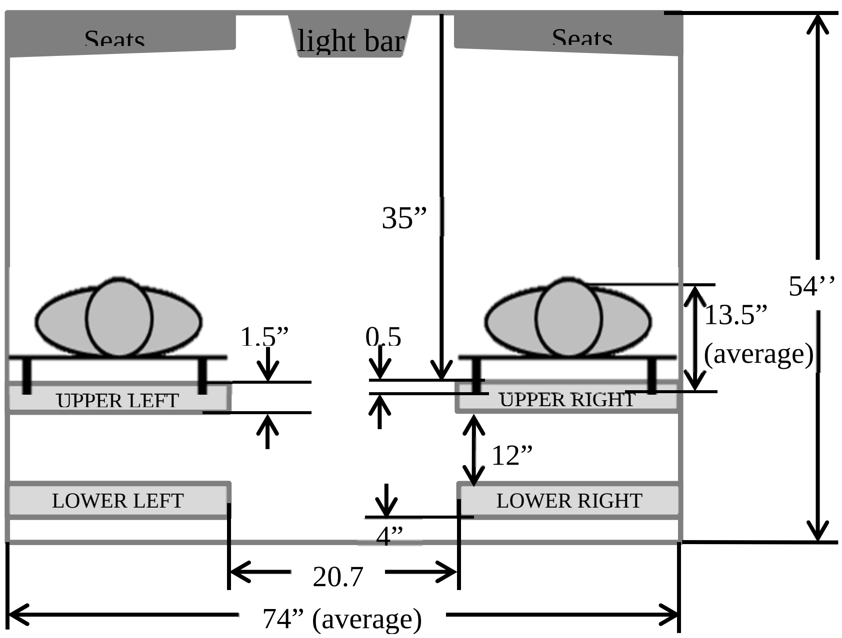


Figure A-2. Aft view–HH-60 with medical interior–SC 5 and 6-full dimensions.

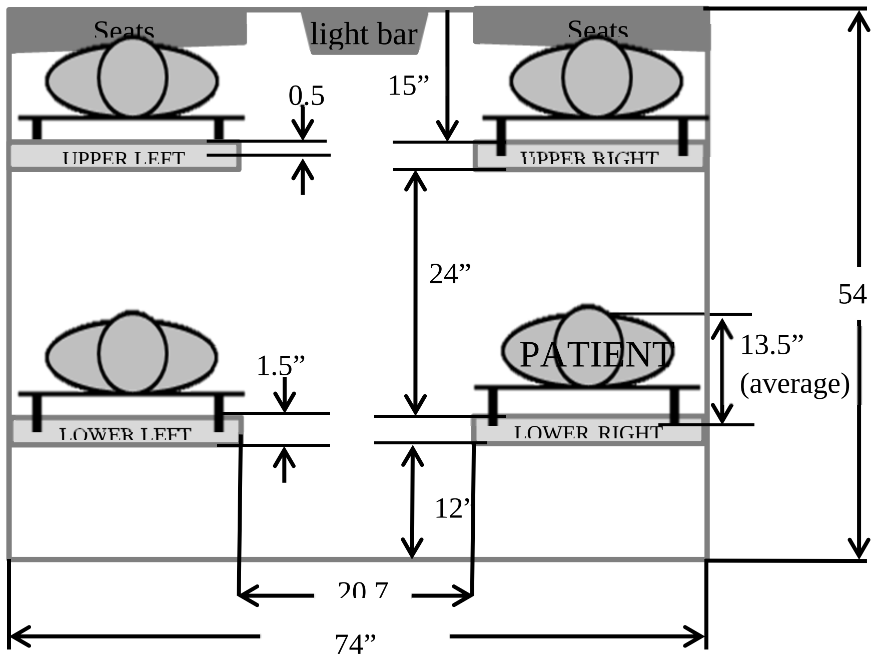


Figure A-3. Aft view–HH-60 with medical interior–SC 7–full dimensions.

Appendix B.

10-step workflow process for E2C2 data acquisition.

This page intentionally left blank.

Appendix B.

10-step workflow process for E2C2 data acquisition.

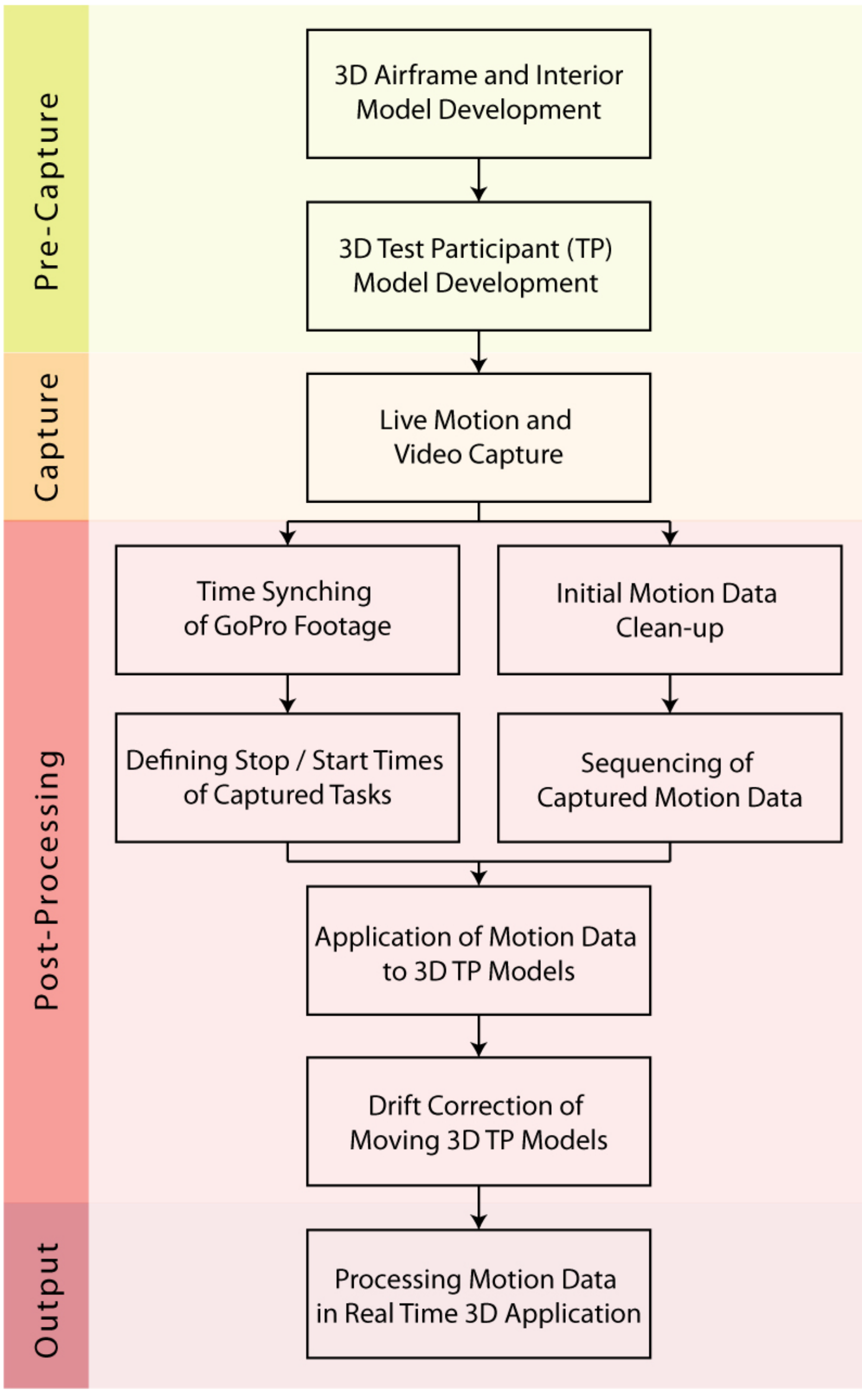


Figure B-1. 10-step workflow process for E2C2 data acquisition.

This page intentionally left blank.

Appendix C.

Movement tracking graphs of all TPs for each scenario.

This page intentionally left blank.

Appendix C.

Movement tracking graphs of all TPs for each scenario.

Table C-1.
Scenario 1 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99th percentile Medic	- 2 SDs	0.10	-4.14	-67.75	-15.26	3.30	-44.71	0.80	29.74	-61.59
	Average 99th	17.13	19.01	-25.02	2.32	14.33	-25.43	14.72	37.22	-27.63
	+ 2 SDs	34.17	42.16	17.70	19.90	25.37	-6.16	28.64	44.71	6.33
TP C1 80th percentile Medic	- 2 SDs	-5.09	-1.22	-55.81	-18.05	4.06	-46.26	-6.02	26.00	-50.89
	Average 80th	14.36	19.64	-18.61	1.58	13.75	-24.12	11.57	35.11	-26.45
	+ 2 SDs	33.81	40.50	18.59	21.21	23.43	-1.98	29.16	44.22	-2.02
TP B 2nd percentile Medic	- 2 SDs	-8.73	-3.38	-64.66	-15.03	3.54	-49.11	-8.92	19.35	-60.81
	Avgerage 2nd	12.49	15.20	-23.22	6.05	12.84	-24.27	9.36	29.09	-23.80
	+ 2 SDs	33.71	33.77	18.21	27.14	22.15	0.57	27.64	38.83	13.22
	minimum distance used (-2SD)	-8.73	-4.14	-67.75	-18.05	3.30	-49.11	-8.92	19.35	-61.59
	maximum distance used (+2SD)	34.17	42.16	18.59	27.14	25.37	0.57	29.16	44.71	13.22

* Floor at y = -0.3 inches

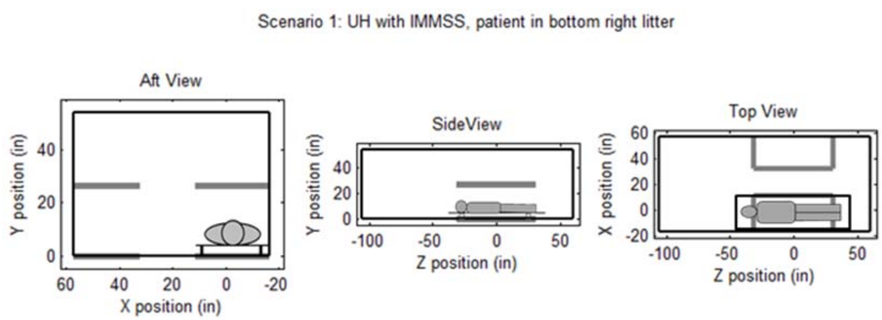


Figure C-1. Scenario 1: UH-60 with Interim MEDEVAC Mission Support System (IMMUS), patient in bottom right litter.

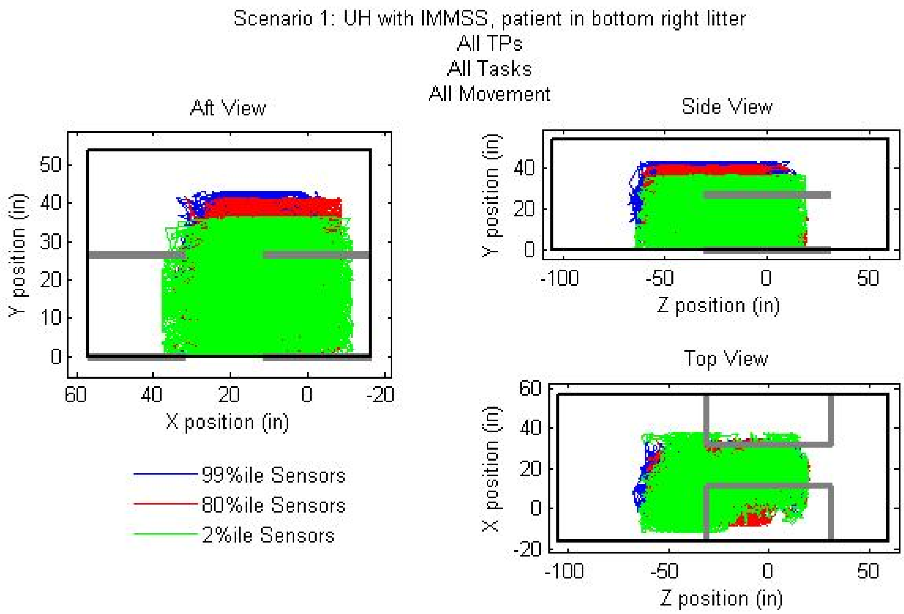


Figure C-2. Scenario 1: UH-60 with IMMSS, patient in bottom right litter (all TPs, all tasks, all movement).

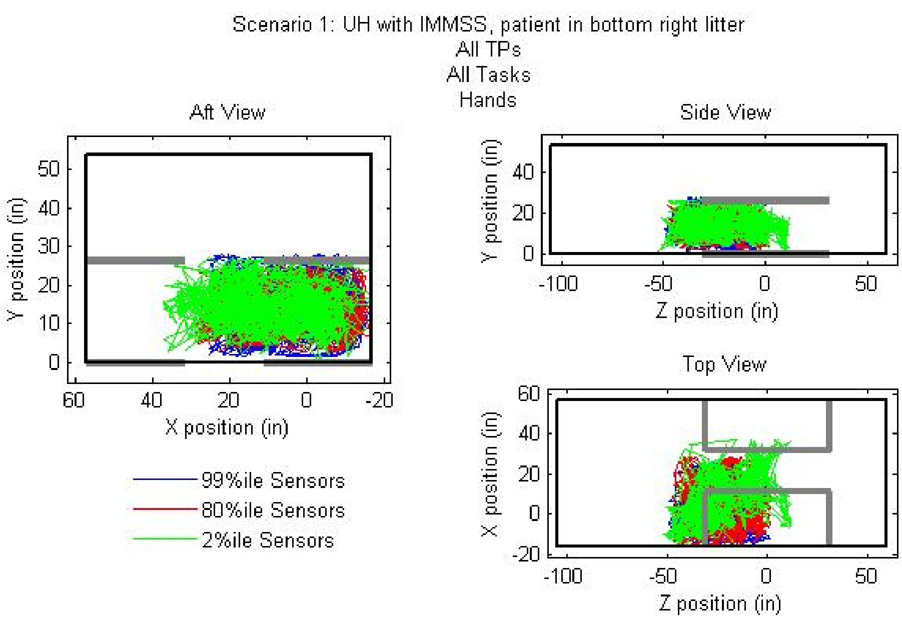


Figure C-3. Scenario 1: UH-60 with IMMSS, patient in bottom right litter (all TPs, all tasks, hands).

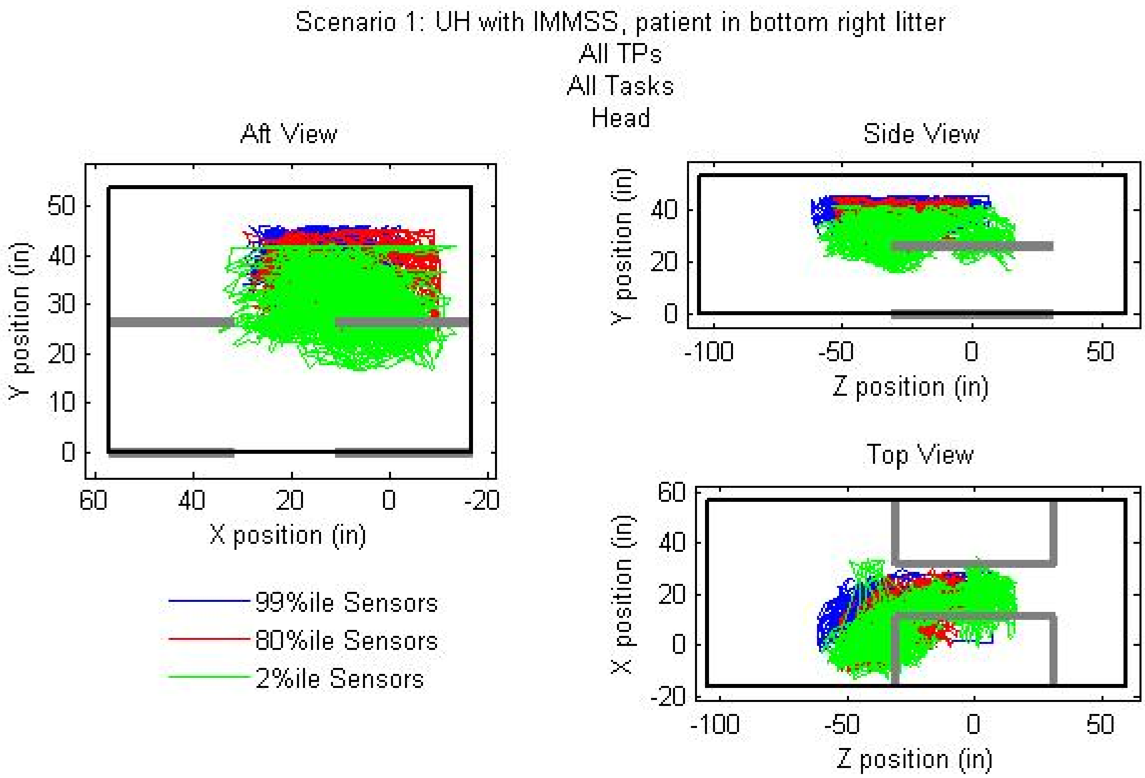


Figure C-4. Scenario 1: UH-60 with IMMSS, patient in bottom right litter (all TPs, all tasks, head).

Table C-2.
Scenario 2 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99th percentile Medic	- 2 SDs	-1.03	-27.91	-52.30	-16.03	-4.42	-32.88	-4.03	9.67	-45.08
	Average 99th	17.00	3.03	-15.28	3.45	9.96	-14.27	14.98	19.29	-16.07
	+ 2 SDs	35.03	33.97	21.74	22.93	24.34	4.35	33.98	28.91	12.93
TP C1 80th percentile Medic	- 2 SDs	-7.47	-29.73	-59.08	-14.98	-2.30	-43.33	-4.17	16.35	-54.31
	Average 80th	12.78	3.33	-21.61	2.60	8.01	-19.81	11.38	21.90	-19.19
	+ 2 SDs	33.04	36.39	15.85	20.18	18.33	3.72	26.92	27.45	15.92
TP B 2nd percentile Medic	- 2 SDs	0.63	-29.46	-38.09	-15.08	-3.72	-37.42	-6.36	14.87	-37.14
	Avgerage 2nd	17.05	2.19	-12.67	5.04	6.62	-16.30	11.27	21.25	-15.44
	+ 2 SDs	33.46	33.84	12.75	25.16	16.96	4.83	28.89	27.64	6.25
	minimum distance used (+2SD)	-7.47	-29.73	-59.08	-16.03	-4.42	-43.33	-6.36	9.67	-54.31
	maximum distance used (-2SD)	35.03	36.39	21.74	25.16	24.34	4.83	33.98	28.91	15.92

* Floor at y = -27.8 inches

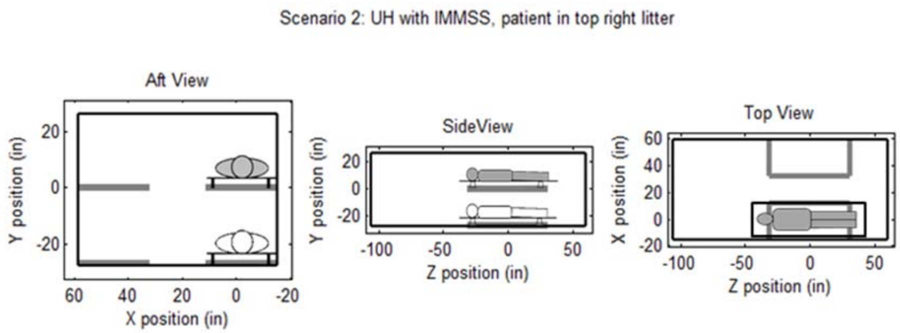


Figure C-5. Scenario 2: UH-60 with IMMUS, patient in top right litter.

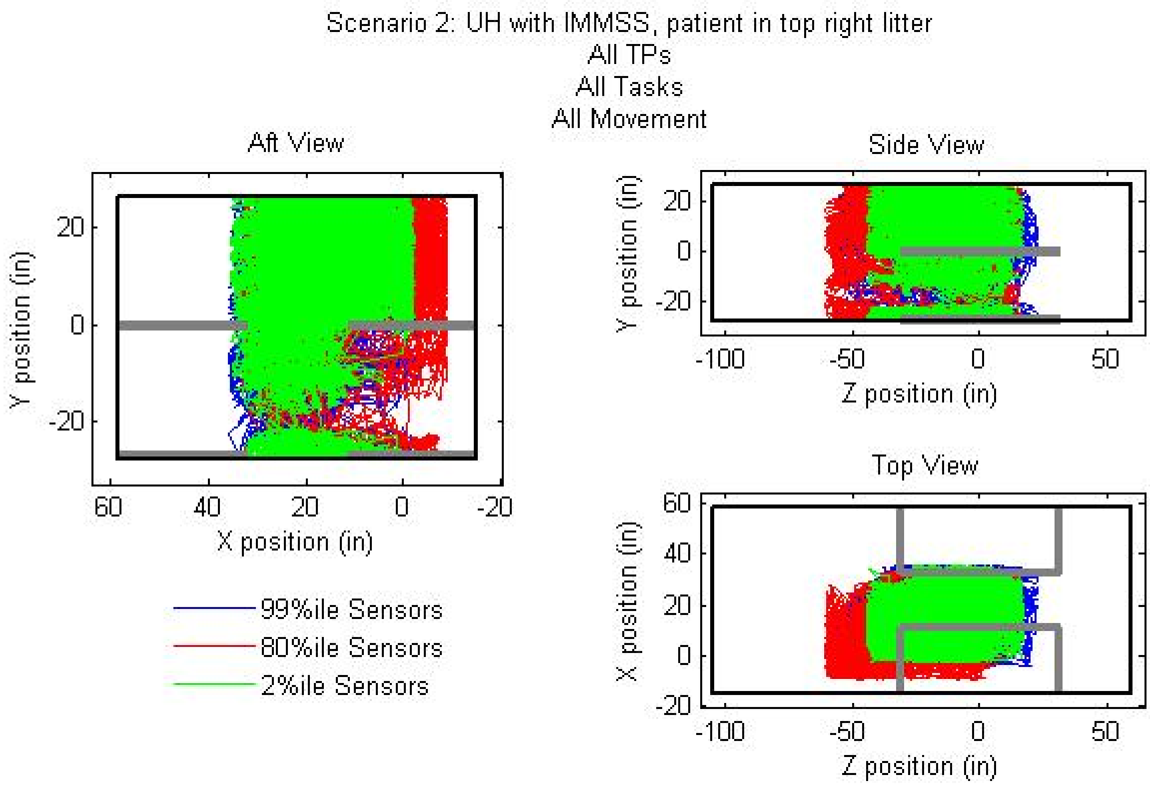


Figure C-6. Scenario 2: UH-60 with IMMSS, patient in top right litter (all TPs, all tasks, all movement).

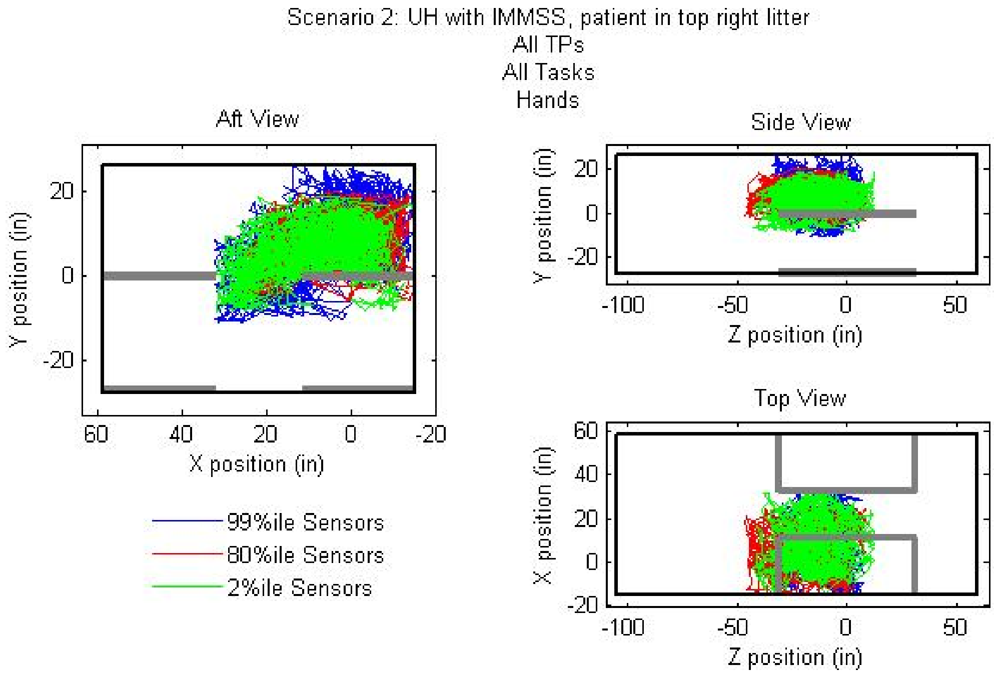


Figure C-7. Scenario 2: UH-60 with IMMSS, patient in top right litter (all TPs, all tasks, hands).

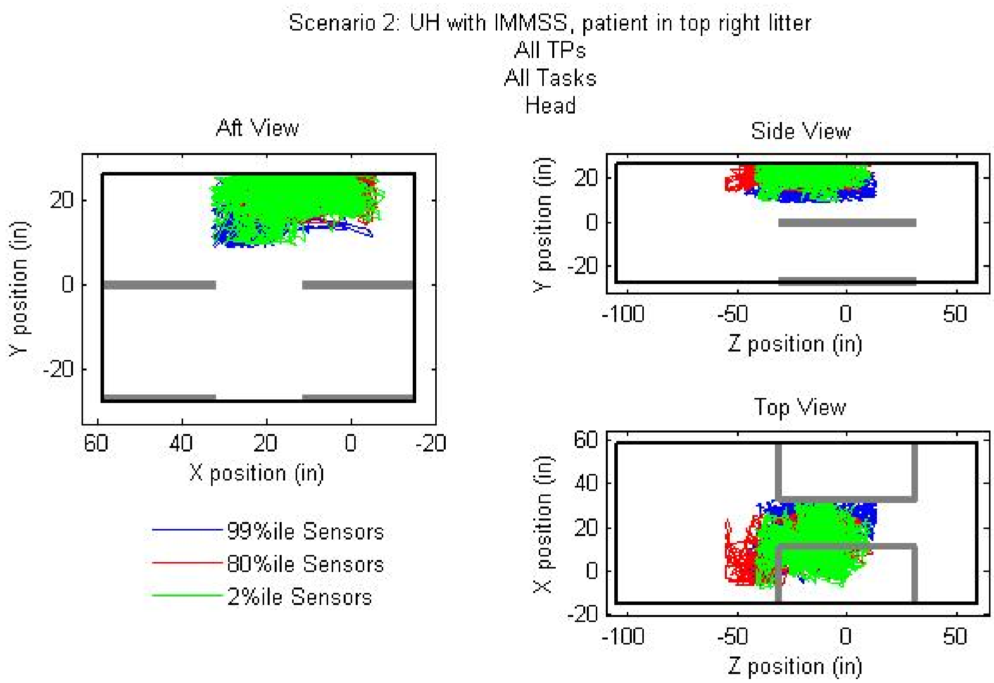


Figure C-8. Scenario 2: UH-60 with IMMSS, patient in top right litter (all TPs, all tasks, head).

Table C-3.

Scenario 3 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99^{th} percentile Medic	- 2 SDs	3.26	-5.16	-39.52	-13.63	-1.32	-37.15	1.10	22.52	-38.05
	Average 99th	18.56	19.49	-5.78	3.37	17.66	-12.52	16.41	35.70	-8.51
	+ 2 SDs	33.85	44.14	27.96	20.38	36.65	12.11	31.71	48.88	21.04
TP C1 80^{th} percentile Medic	- 2 SDs	4.05	-2.77	-39.36	-14.47	4.05	-43.14	1.01	24.53	-43.41
	Average 80th	18.16	19.94	-14.71	3.38	13.61	-23.10	13.67	35.71	-23.33
	+ 2 SDs	32.27	42.65	9.95	21.23	23.17	-3.06	26.33	46.90	-3.25
TP- B 2^{nd} percentile Medic	- 2 SDs	-5.88	-4.04	-59.45	-11.88	5.06	-46.25	-4.56	20.04	-57.41
	Avgerage 2nd	12.23	15.46	-27.86	2.06	12.63	-27.88	8.51	28.78	-32.40
	+ 2 SDs	30.35	34.97	3.73	16.00	20.20	-9.50	21.58	37.51	-7.39
	minimum distance used (+2SD)	-5.88	-5.16	-59.45	-14.47	-1.32	-46.25	-4.56	20.04	-57.41
	maximum distance used (-2SD)	33.85	44.14	27.96	21.23	36.65	12.11	31.71	48.88	21.04

* Floor at y = -0.3 inches

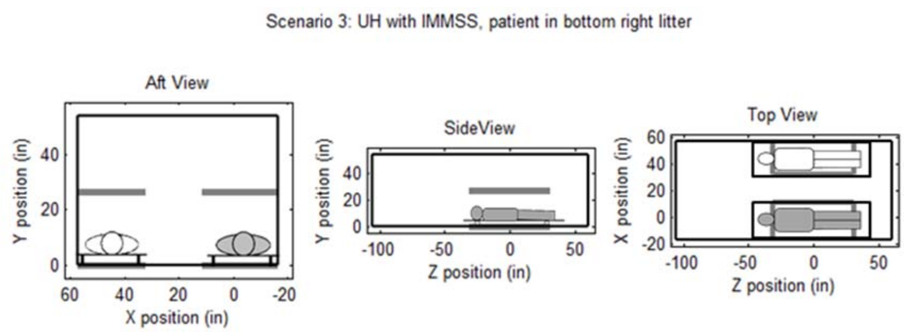


Figure C-9. Scenario 3: UH-60 with IMMUS, patient in bottom right litter.

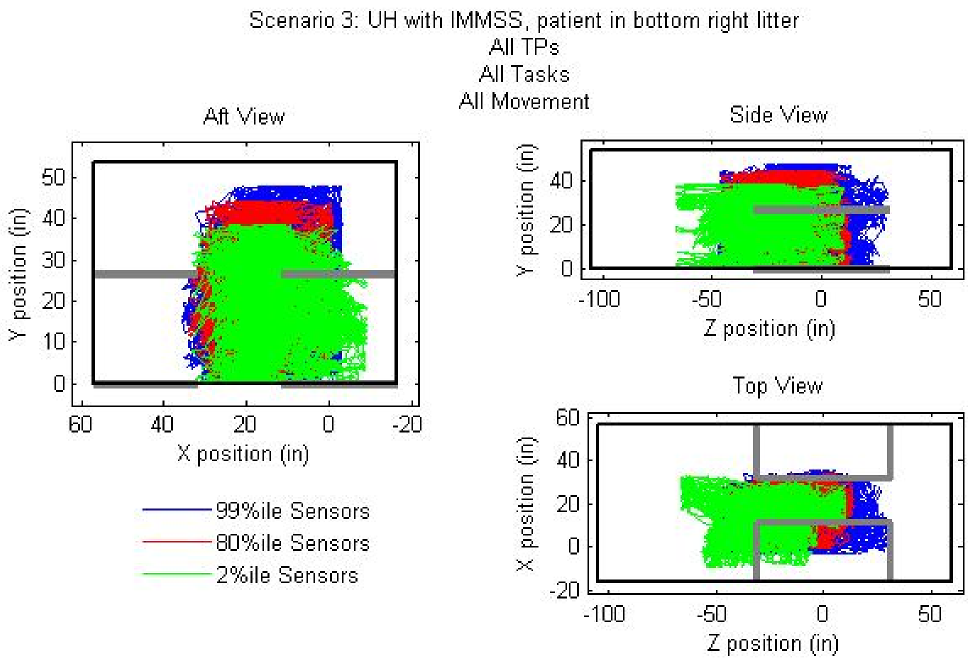


Figure C-10. Scenario 3: UH-60 with IMMSS, patient in bottom right litter (all TPs, all tasks, all movements).

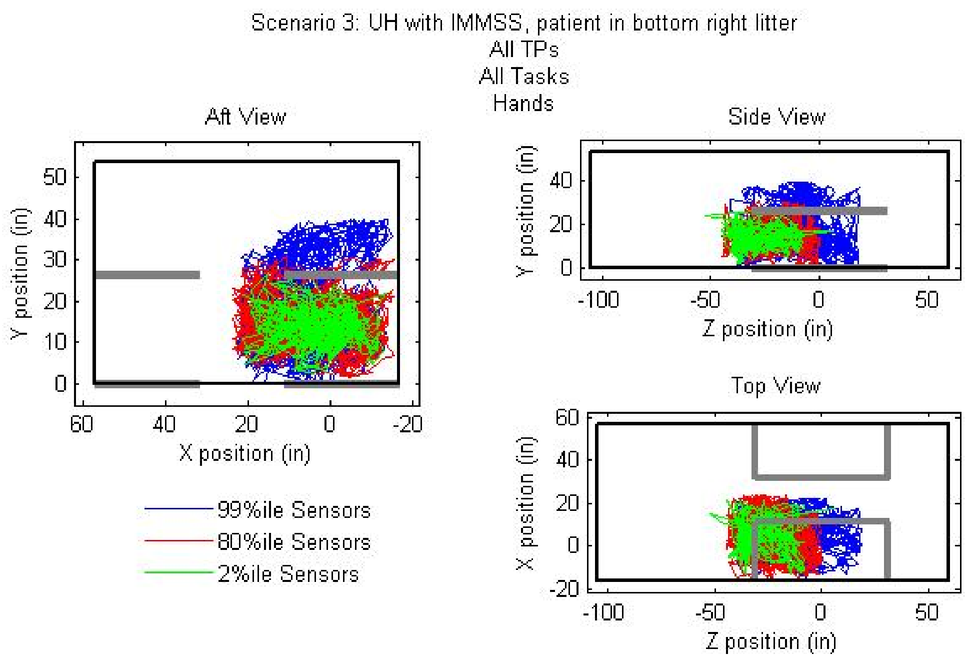


Figure C-11. Scenario 3: UH-60 with IMMSS, patient in bottom right litter (all TPs, all tasks, hands).

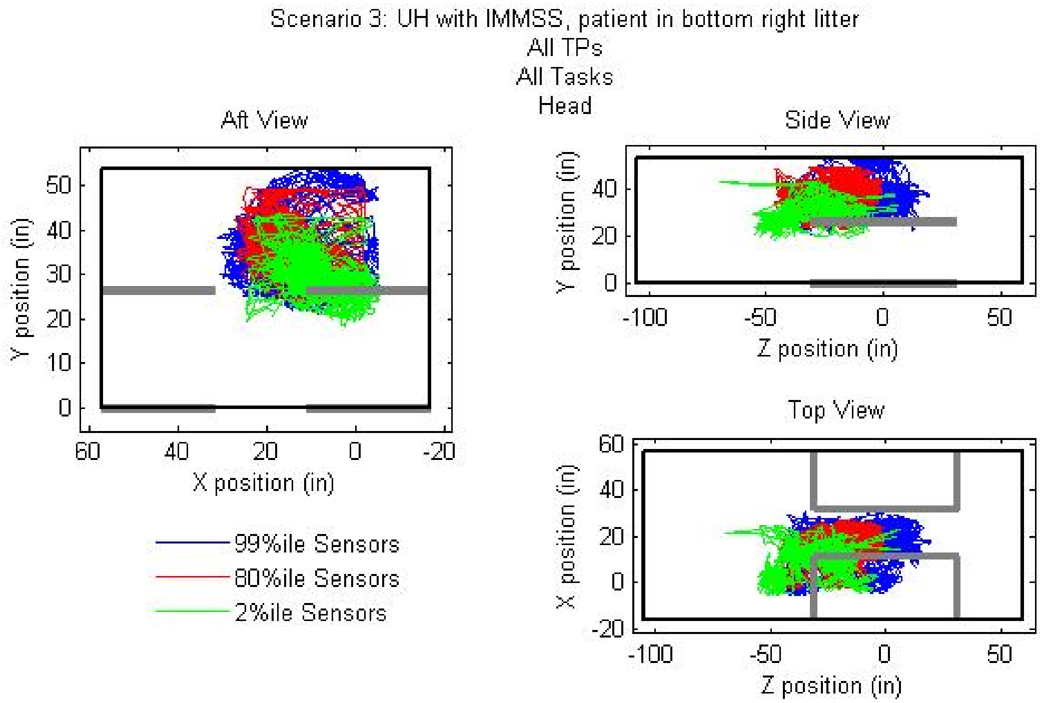


Figure C-12. Scenario 3: UH-60 with IMMSS, patient in bottom right litter (all TPs, all tasks, head).

<u>Table C-4.</u>
Scenario 4 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99th percentile Medic	- 2 SDs	6.36	-3.75	-32.67	-8.51	0.53	-40.69	4.14	29.13	-37.77
	Average 99th	24.43	18.79	-10.44	10.26	10.05	-13.20	19.32	36.62	-12.34
	+ 2 SDs	42.51	41.34	11.78	29.02	19.57	14.28	34.50	44.11	13.10
TP C2 75th percentile Medic	- 2 SDs	9.38	-2.23	-32.16	-3.39	7.44	-35.60	6.04	30.59	-34.82
	Average 80th	26.33	20.97	-8.57	13.62	15.62	-11.38	20.02	38.00	-10.88
	+ 2 SDs	43.29	44.17	15.02	30.62	23.79	12.84	33.99	45.41	13.05
TP B 2nd percentile Medic	- 2 SDs	-5.20	-2.58	-25.09	-14.16	5.72	-25.41	-10.19	24.18	-29.08
	Avgerage 2nd	17.44	17.79	-3.95	4.32	15.59	-2.39	9.87	32.69	-4.85
	+ 2 SDs	40.07	38.17	17.18	22.81	25.45	20.62	29.93	41.20	19.39
	minimum distance used (+2SD)	-5.20	-3.75	-32.67	-14.16	0.53	-40.69	-10.19	24.18	-37.77
	maximum distance used (-2SD)	43.29	44.17	17.18	30.62	25.45	20.62	34.50	45.41	19.39

*swapped x and z values for Scenario 4 so z goes along patient
* Floor at y = 0.0 inches

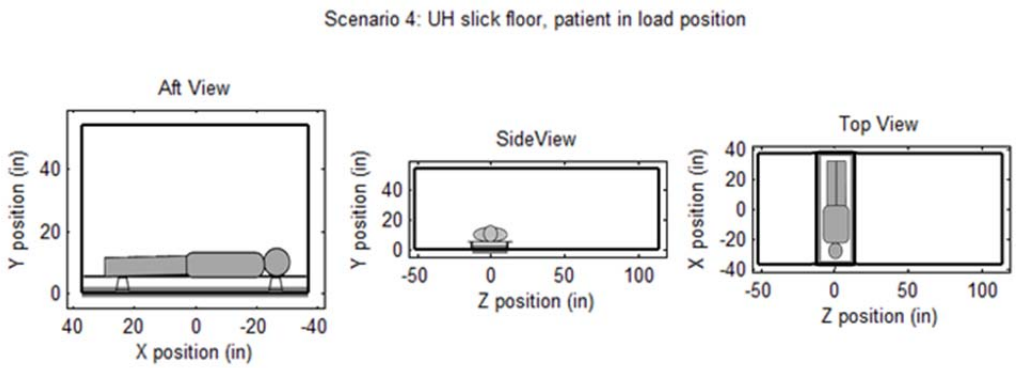
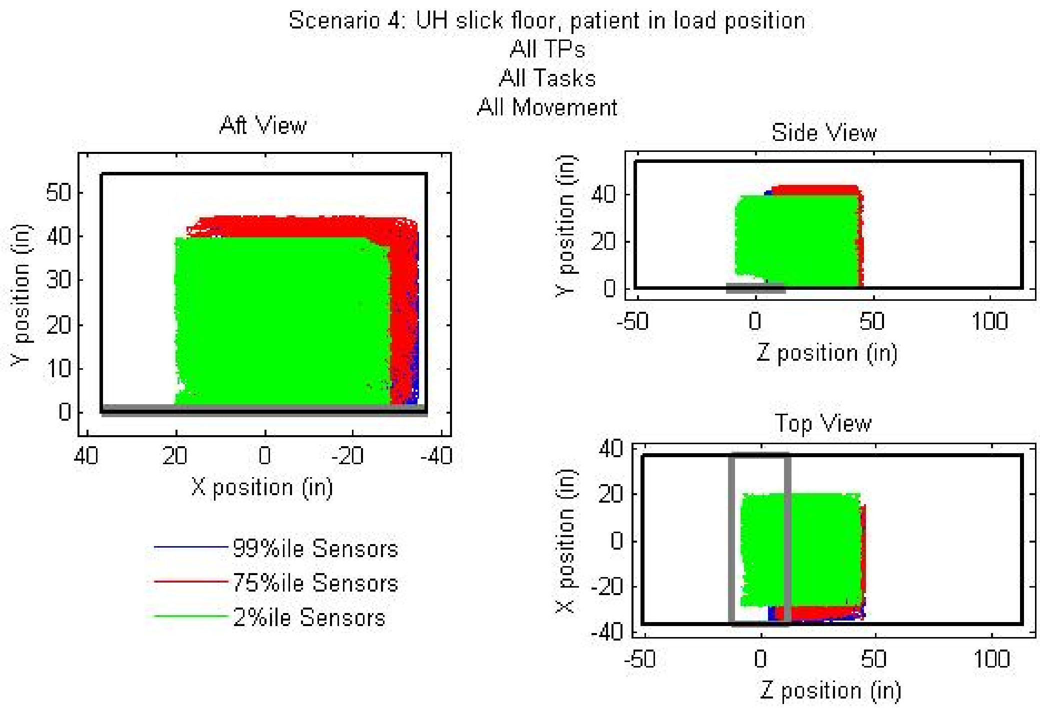


Figure C-13. Scenario 4: UH-60 slick, patient in load position.



.

Figure C-14. Scenario 4: UH-60 slick, patient in load position (all TPs, all tasks, all movements).

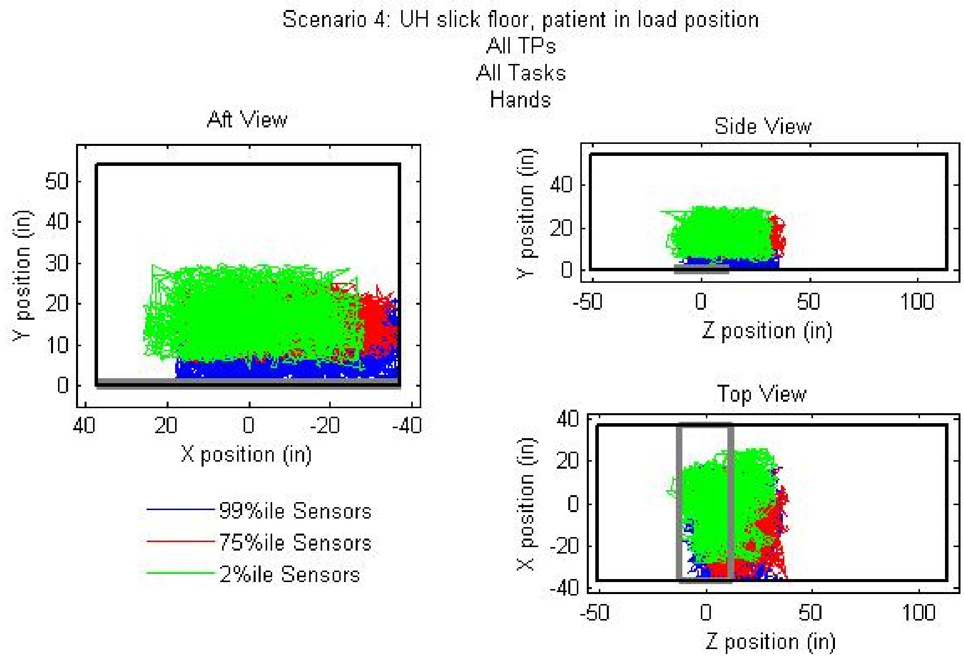


Figure C-15. Scenario 4: UH-60 slick, patient in load position (all TPs, all tasks, hands).

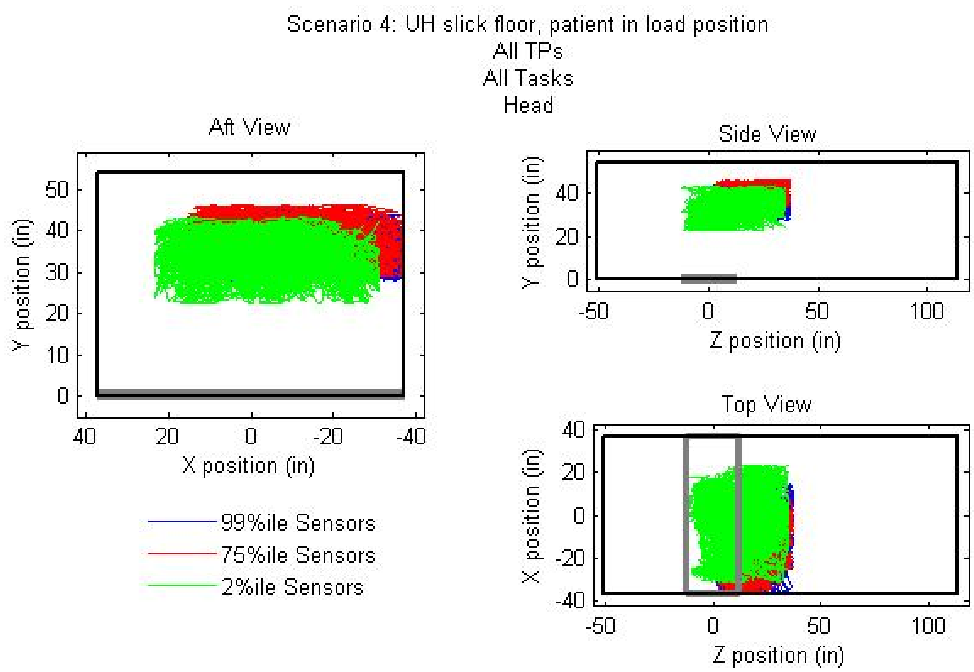


Figure C-16. Scenario 4: UH-60 slick, patient in load position (all TPs, all tasks, head).

Table C-5.
Scenario 5 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99th percentile Medic	- 2 SDs	-3.50	-20.80	-53.31	-18.09	-6.19	-47.84	-12.77	14.93	-53.36
	Average 99th	16.77	8.48	-19.14	2.75	5.73	-17.43	7.48	24.31	-22.57
	+ 2 SDs	37.04	37.76	15.03	23.59	17.64	12.98	27.73	33.70	8.22
TP C2 75th percentile Medic	- 2 SDs	-5.74	-21.03	-44.67	-13.56	-0.67	-43.73	-14.78	16.83	-51.28
	Average 80th	13.39	10.70	-15.05	1.00	9.22	-16.93	4.65	25.76	-18.92
	+ 2 SDs	32.51	42.42	14.56	15.55	19.12	9.87	24.07	34.68	13.44
TP B 2nd percentile Medic	- 2 SDs	-6.05	-20.18	-56.21	-10.58	1.07	-45.82	-9.17	14.00	-52.68
	Avgerage 2nd	10.97	7.79	-18.45	1.50	8.40	-20.20	4.82	23.41	-22.59
	+ 2 SDs	27.99	35.77	19.31	13.58	15.72	5.41	18.81	32.83	7.49
	minimum distance used (+2SD)	-6.05	-21.03	-56.21	-18.09	-6.19	-47.84	-14.78	14.00	-53.36
	maximum distance used (-2SD)	37.04	42.42	19.31	23.59	19.12	12.98	27.73	34.68	13.44

* Floor at y = -20.0 inches

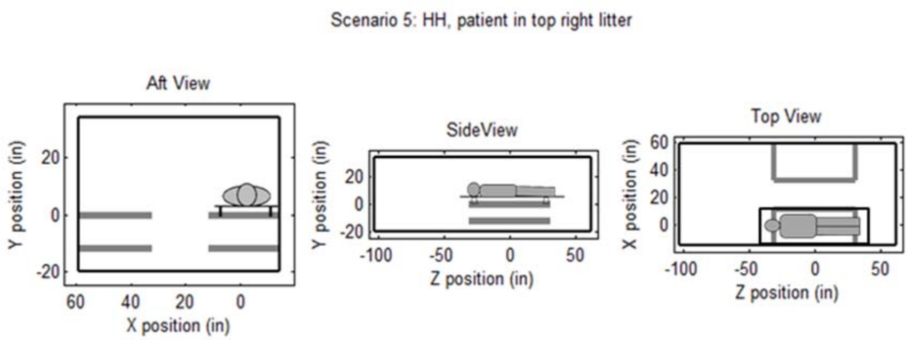


Figure C-17. Scenario 5: HH-60, patient in top right litter.

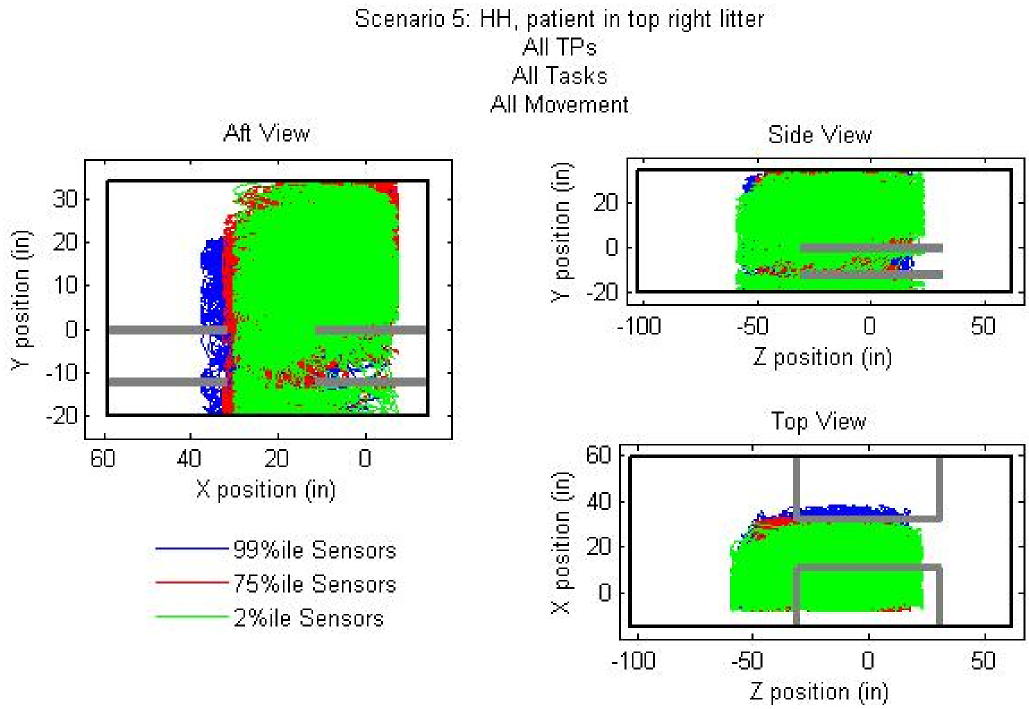


Figure C-18. Scenario 5: HH-60, patient in top right litter (all TPs, all tasks, all movements).

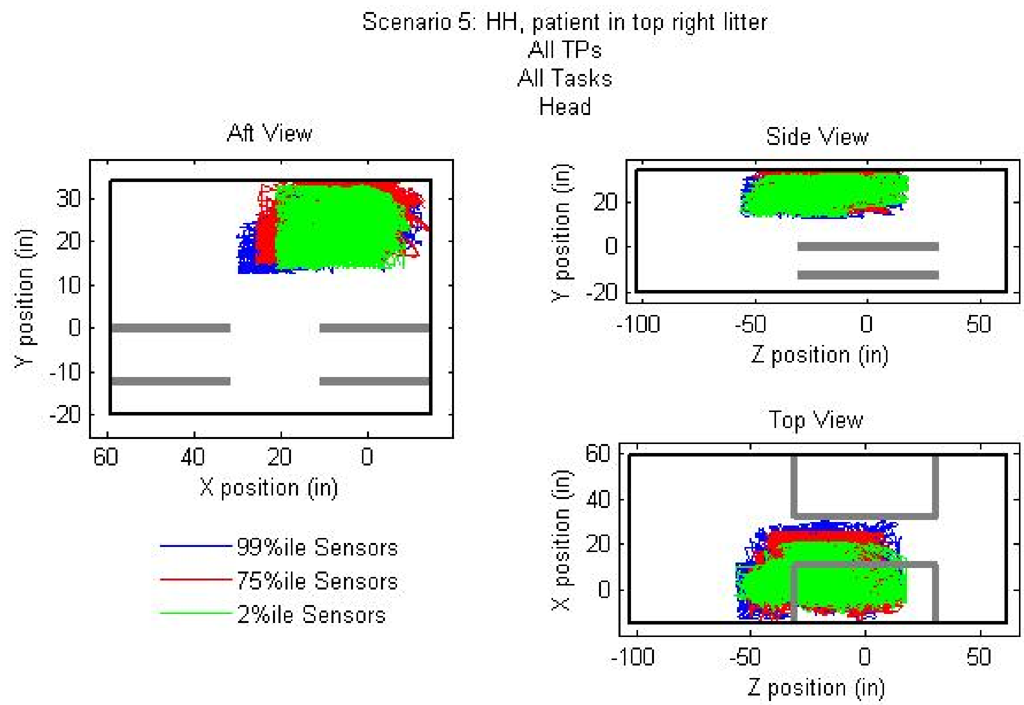


Figure C-19. Scenario 5: HH-60, patient in top right litter (all TPs, all tasks, hands).

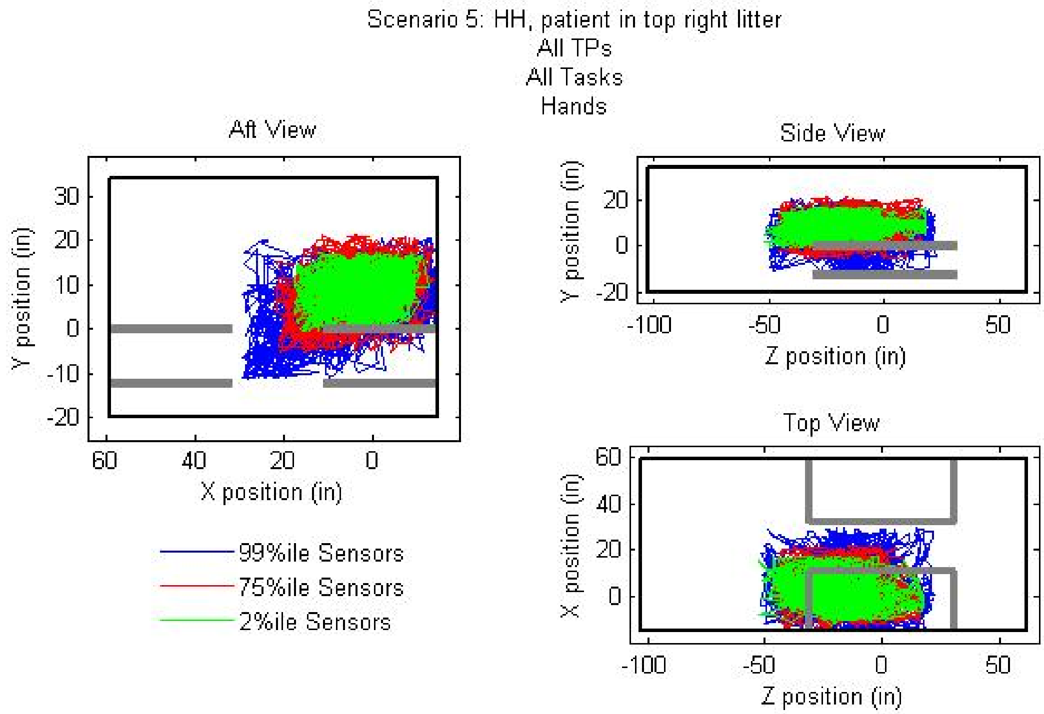


Figure C-20. Scenario 5: HH-60, patient in top right litter (all TPs, all tasks, head).

Table C-6.
Scenario 6 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99th percentile Medic	- 2 SDs	-5.37	-20.52	-46.40	-16.94	-7.99	-45.84	-15.53	15.02	-48.89
	Average 99th	15.06	7.81	-9.96	2.13	4.11	-8.51	6.88	23.08	-14.62
	+ 2 SDs	35.50	36.13	26.49	21.20	16.21	28.82	29.29	31.15	19.64
TP C2 75th percentile Medic	- 2 SDs	-3.90	-22.28	-44.67	-11.58	-3.24	-42.83	-14.64	15.66	-48.08
	Average 80th	14.56	9.68	-14.39	3.26	8.24	-16.79	6.48	25.50	-18.22
	+ 2 SDs	33.02	41.65	15.90	18.10	19.72	9.26	27.59	35.34	11.63
TP B 2nd percentile Medic	- 2 SDs	-6.36	-21.16	-54.53	-11.89	1.15	-44.38	-9.70	14.10	-54.29
	Avgerage 2nd	11.93	6.88	-19.98	1.07	8.83	-22.41	5.65	23.01	-24.19
	+ 2 SDs	30.22	34.92	14.58	14.03	16.50	-0.44	21.01	31.93	5.92
	minimum distance used (+2SD)	-6.36	-22.28	-54.53	-16.94	-7.99	-45.84	-15.53	14.10	-54.29
	maximum distance used (-2SD)	35.50	41.65	26.49	21.20	19.72	28.82	29.29	35.34	19.64

* Floor at y = -20.0 inches

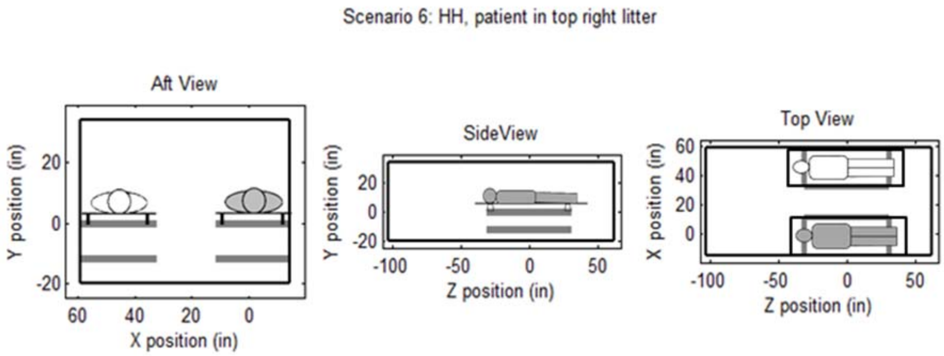


Figure C-21. Scenario 6: HH-60, patient in top right litter.

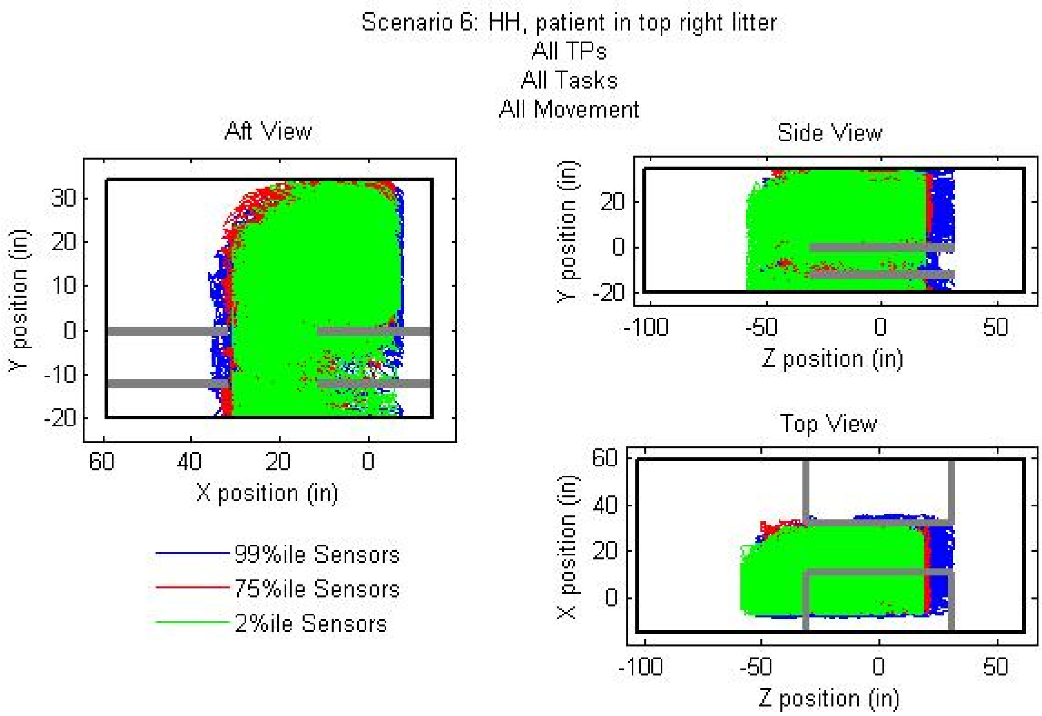


Figure C-22. Scenario 6: HH-60, patient in top right litter (all TPs, all tasks, all movements).

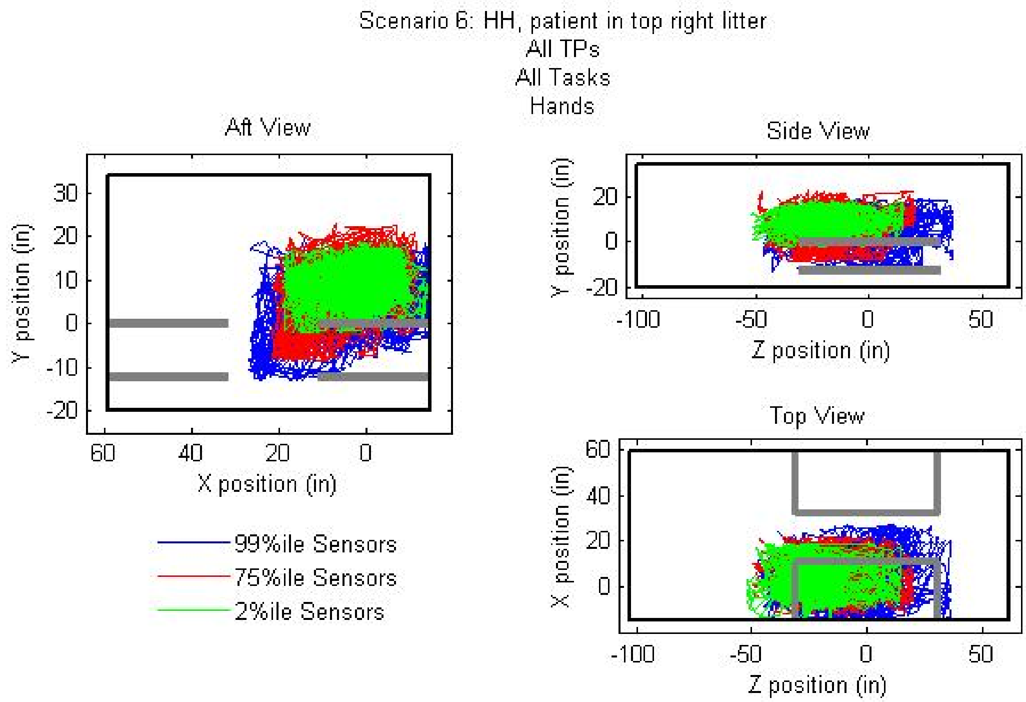


Figure C-23. Scenario 6: HH-60, patient in top right litter (all TPs, all tasks, hands).

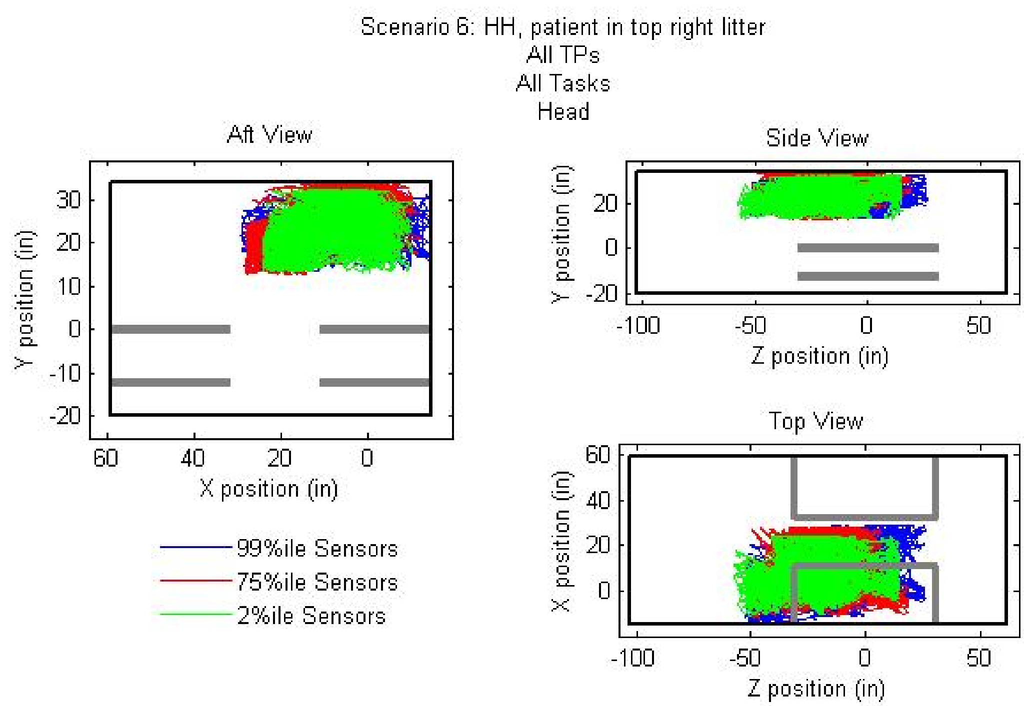


Figure C-24. Scenario 6: HH-60, patient in top right litter (all TPs, all tasks, head).

<u>Table C-7.</u>
Scenario 7 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99th percentile Medic	- 2 SDs	2.74	-17.76	-54.71	-14.13	-5.91	-44.13	3.92	19.91	-52.20
	Average 99th	18.72	7.24	-15.32	2.06	5.58	-18.06	18.12	25.97	-16.07
	+ 2 SDs	34.70	32.24	24.06	18.24	17.07	8.01	32.32	32.03	20.06
TP C2 75th percentile Medic	- 2 SDs	2.00	-15.32	-46.15	-11.11	-1.41	-42.88	0.45	17.74	-45.91
	Average 80th	18.73	7.41	-19.11	5.52	6.60	-15.99	17.15	24.51	-17.94
	+ 2 SDs	35.46	30.14	7.94	22.15	14.61	10.89	33.86	31.27	10.03
TP B 2nd percentile Medic	- 2 SDs	-5.56	-15.81	-48.25	-11.08	-1.01	-39.65	-4.85	15.53	-46.19
	Avgerage 2nd	15.96	6.48	-10.85	2.38	6.95	-9.63	10.96	21.71	-11.14
	+ 2 SDs	37.47	28.77	26.56	15.84	14.92	20.39	26.77	27.89	23.91
	minimum distance used (+2SD)	-5.56	-17.76	-54.71	-14.13	-5.91	-44.13	-4.85	15.53	-52.20
	maximum distance used (-2SD)	37.47	32.24	26.56	22.15	17.07	20.39	33.86	32.03	23.91

* Floor at y = -14.0 inches

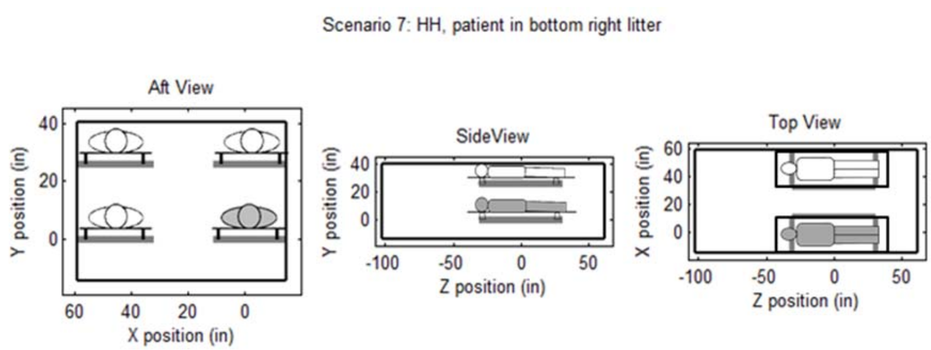


Figure C-25. Scenario 7: HH-60, patient in bottom right litter.

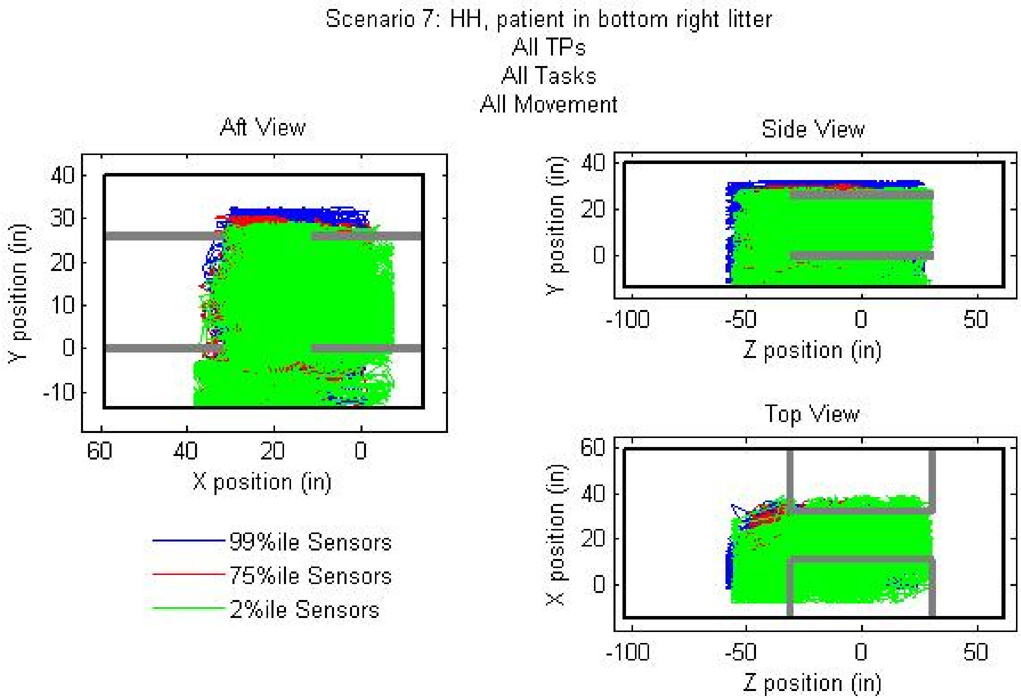


Figure C-26. Scenario 7: HH-60, patient in bottom right litter (all TPs, all tasks, all movements).

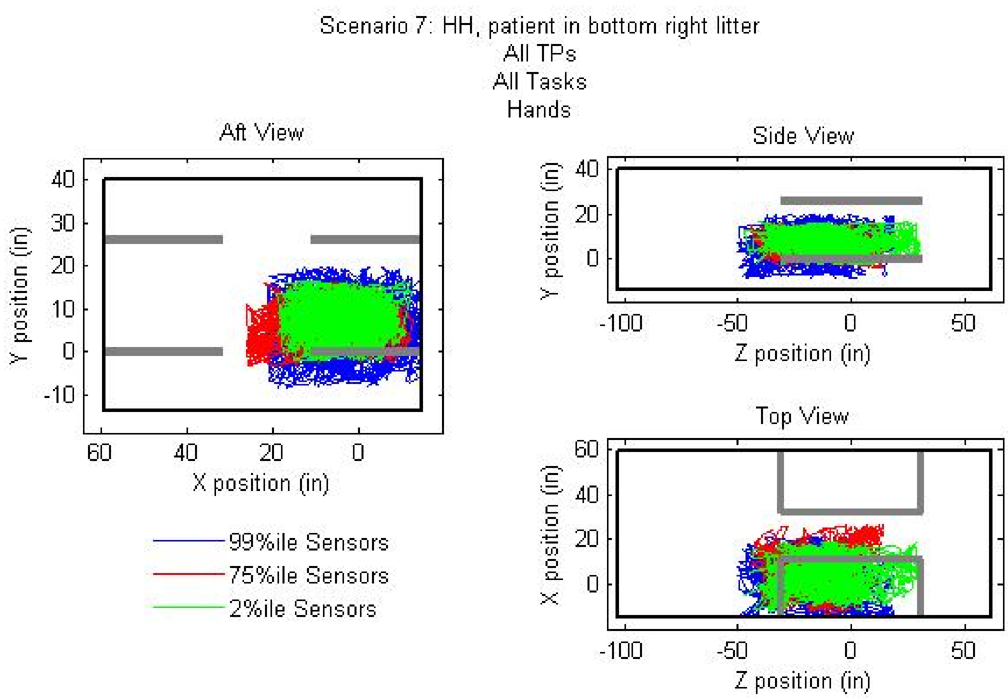


Figure C-27. Scenario 7: HH-60, patient in bottom right litter (all TPs, all tasks, hands).

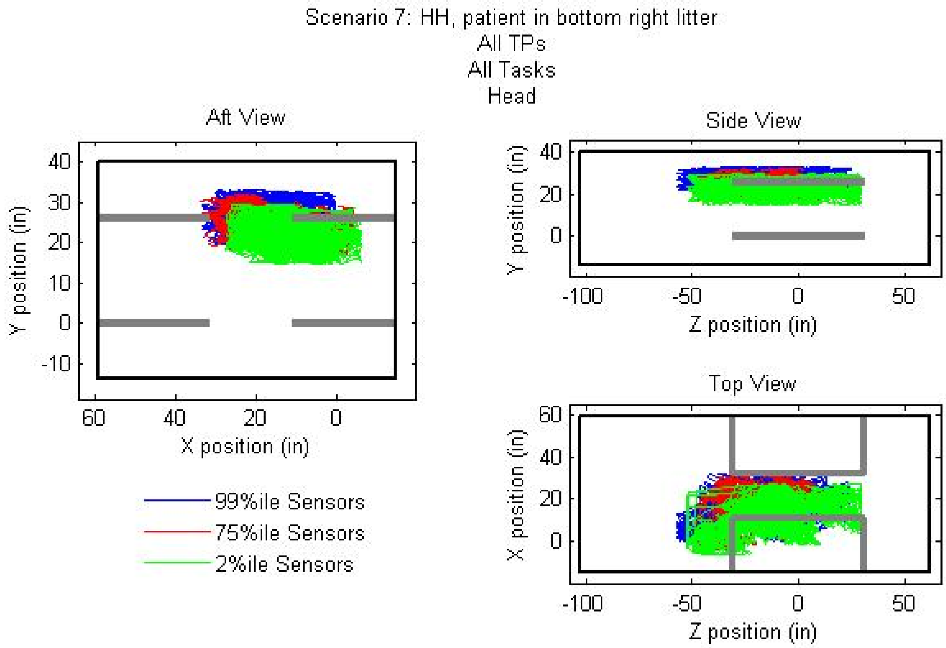


Figure C-28. Scenario 7: HH-60, patient in bottom right litter (all TPs, all tasks, hands).

Table C-8.
Scenario 8 data.

		All Movement			Hands			Head		
		X	Y	Z	X	Y	Z	X	Y	Z
TP A 99th percentile Medic	- 2 SDs	-7.39	-27.72	-60.91	-11.89	-8.21	-41.55	-7.67	10.04	-60.11
	Average 99th	14.76	2.07	-23.13	3.56	5.70	-21.54	10.08	18.48	-24.55
	+ 2 SDs	36.91	31.85	14.64	19.02	19.60	-1.54	27.84	26.93	11.01

* Floor at y = -27.8 inches

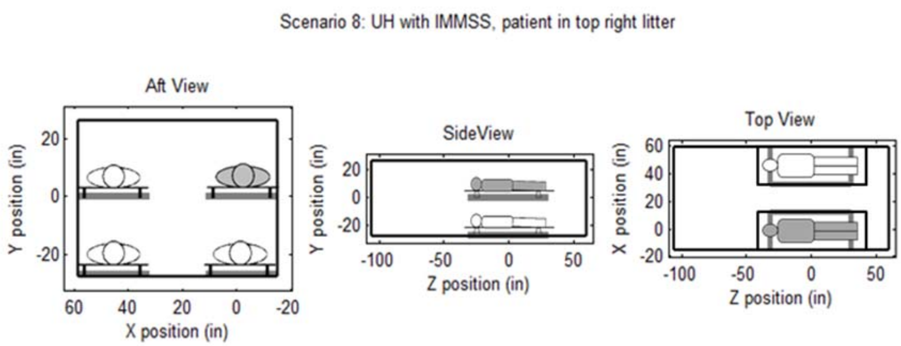


Figure C-29. Scenario 8: UH-60 with IMMSS, patient in top right litter.

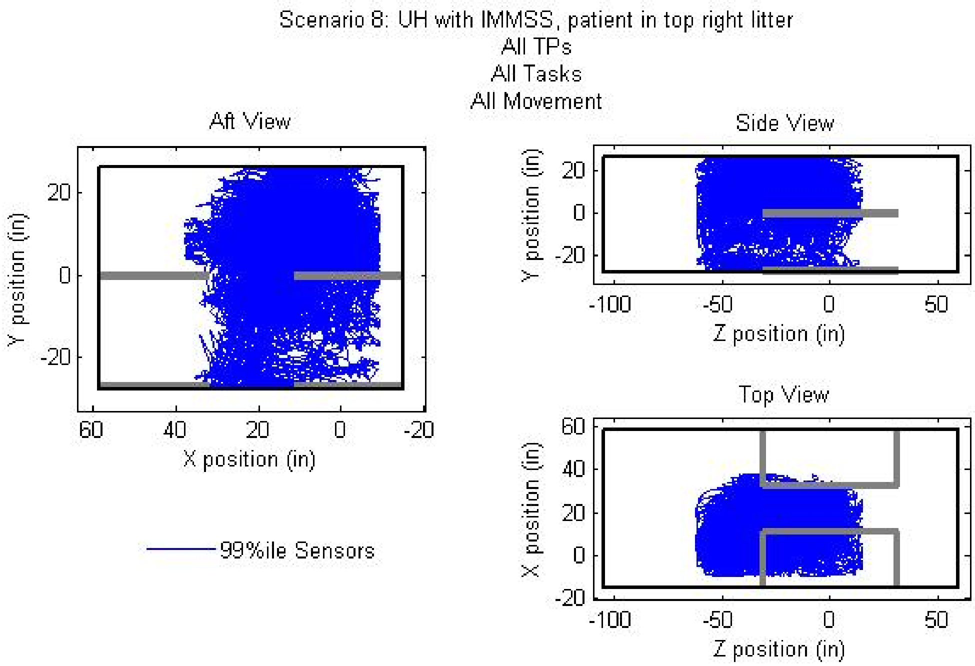


Figure C-30. Scenario 8: UH-60 with IMMSS, patient in top right litter (all TPs, all tasks, all movements).

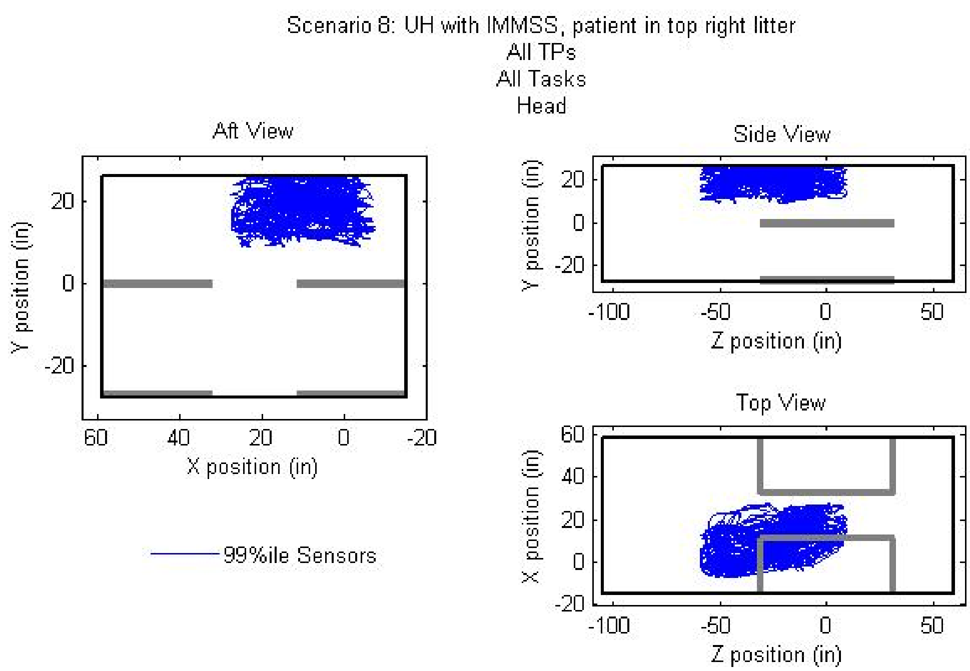


Figure C-31. Scenario 8: UH-60 with IMMSS, patient in top right litter (all TPs, all tasks, hands).

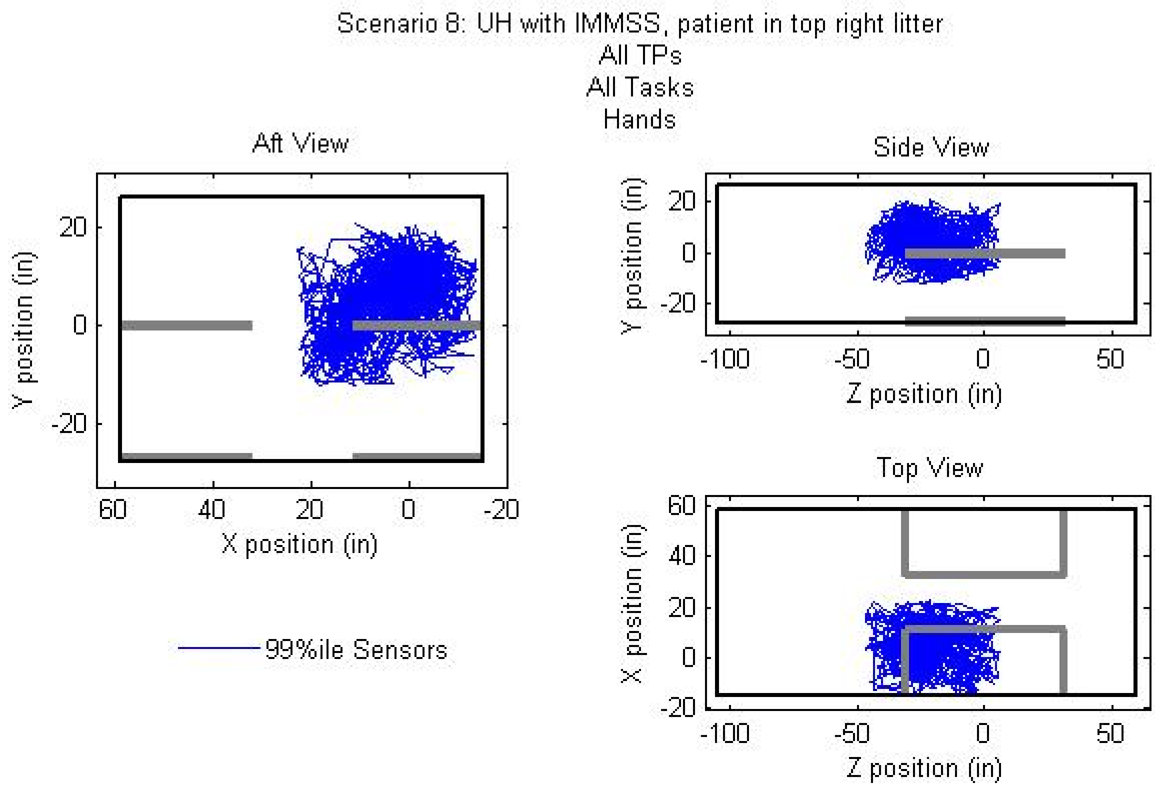


Figure C-32. Scenario 8: UH-60 with IMMSS, patient in top right litter (all TPs, all tasks, head).

Appendix D.

Neck and back bend graphs.

This page intentionally left blank.

Appendix D.

Neck and back bend graphs.

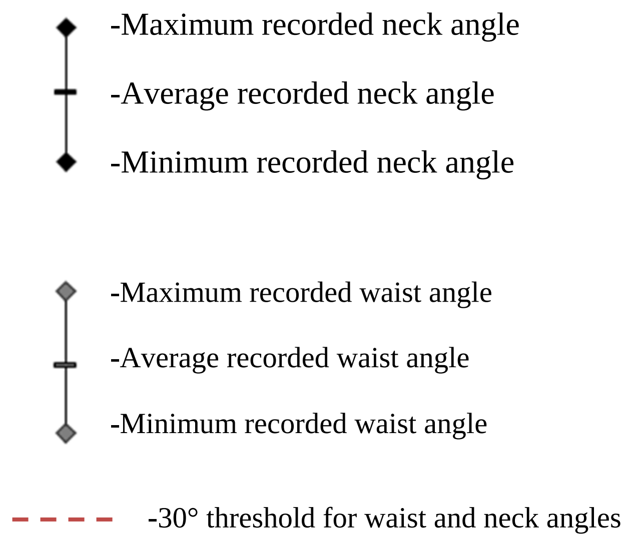


Figure D-1. Graph legend.

$$\text{Average Neck Angle} = \frac{\sum(\text{Average Neck Bend per Task} * \text{Task Duration})}{\sum \text{Task Durations for the Full Scenario}}$$

$$\text{Average Back Angle} = \frac{\sum(\text{Average Back Bend per Task} * \text{Task Duration})}{\sum \text{Task Durations for the Full Scenario}}$$

$$\%\ \text{Time Above Critical Neck Angle} = \frac{\sum \text{Duration Exceeding Threshold for Neck Bend per Task}}{\sum \text{Task Durations for the Full Scenario}}$$

$$\%\ \text{Time Above Critical Back Angle} = \frac{\sum \text{Duration Exceeding Threshold for Back Bend per Task}}{\sum \text{Task Durations for the Full Scenario}}$$

Figure D-2. Graph formulas.

Table D-1.
Neck angle data.

Scenario	TP	Average Angle – Neck	Average Angle - Back	Percent of Time Above Critical Neck Angle (30°)	Percent of Above Critical Back Angle (30°)
1 (Lower IMMSS)	A	31.7°	29.8°	41%	38%
	B	69.6°	37.5°	97%	53%
	C	64.7°	44.1°	96%	79%
2 (Upper IMMSS)	A	38.3°	36.4°	68%	66%
	B	64.8°	27.6°	96%	31%
	C	55.5°	34.4°	69%	66%
3 (Lower IMMSS)	A	38.5°	33.5°	62%	56%
	B	69.6°	24.8°	94%	30%
	C	61.2°	41.7°	91%	71%
4 (Slick floor)	A	33.8°	28.6°	60%	41%
	B	67.4°	24.3°	96%	29%
	C	57.3°	28.6°	96%	33%
5 (2 patients, HH-60)	A	52.7°	49.0°	72%	70%
	B	71.4°	31.0°	94%	58%
	C	78.2°	47.2°	83%	74%
6 (2 patients, HH-60)	A	53.4°	48.3°	69%	66%
	B	69.6°	26.3°	94%	44%
	C	76.0°	44.8°	86%	71%
7 (4 to 6 patient HH-60)	A	24.1°	19.2°	21%	16%
	B	58.7°	21.9°	91%	23%
	C	41.8°	28.1°	73%	46%
8 (Upper IMMSS)	A	41.6°	37.6°	62%	61%

*Calculations and graphs exclude task 1 data.

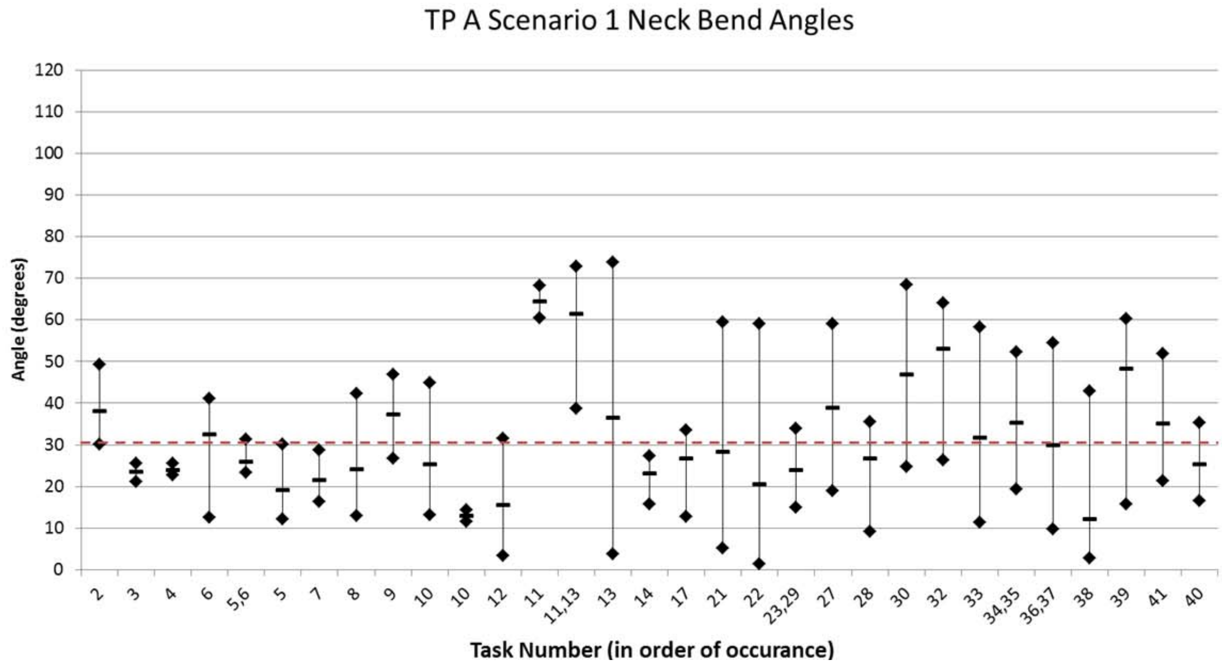


Figure D-3. TP A scenario 1 neck bend angles.

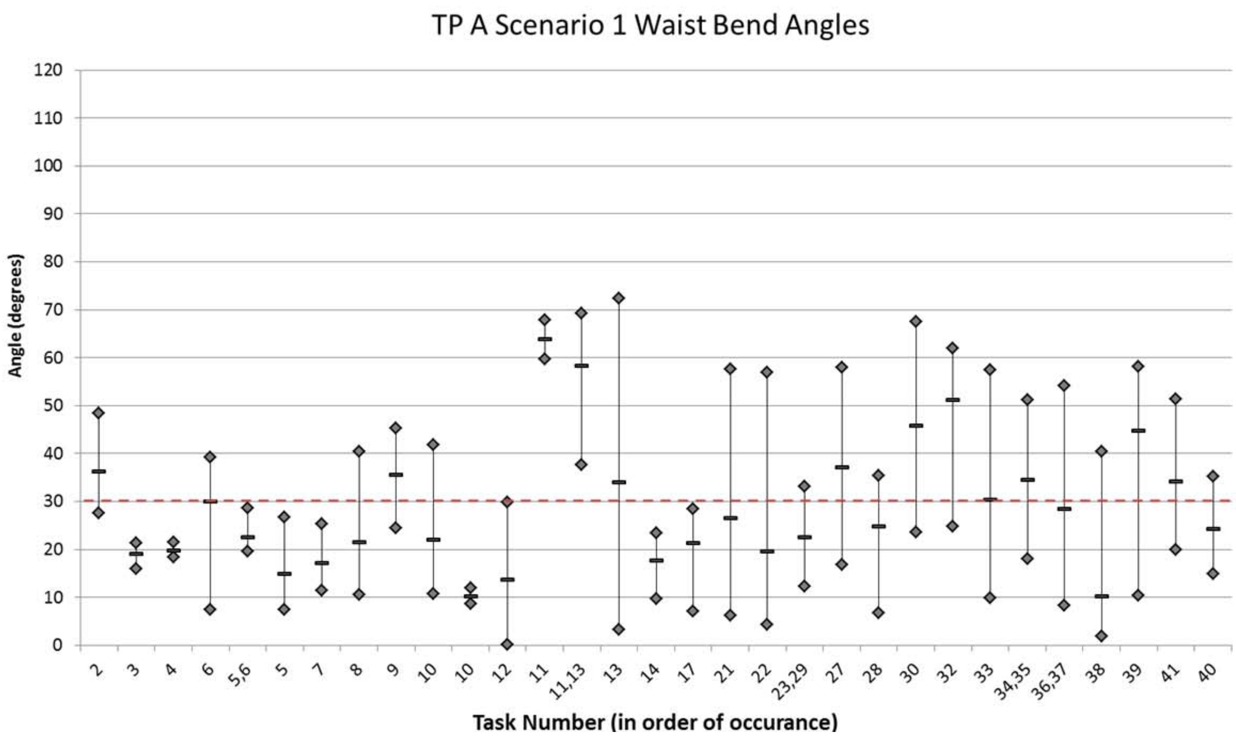


Figure D-4. TP A scenario 1 waist bend angles.

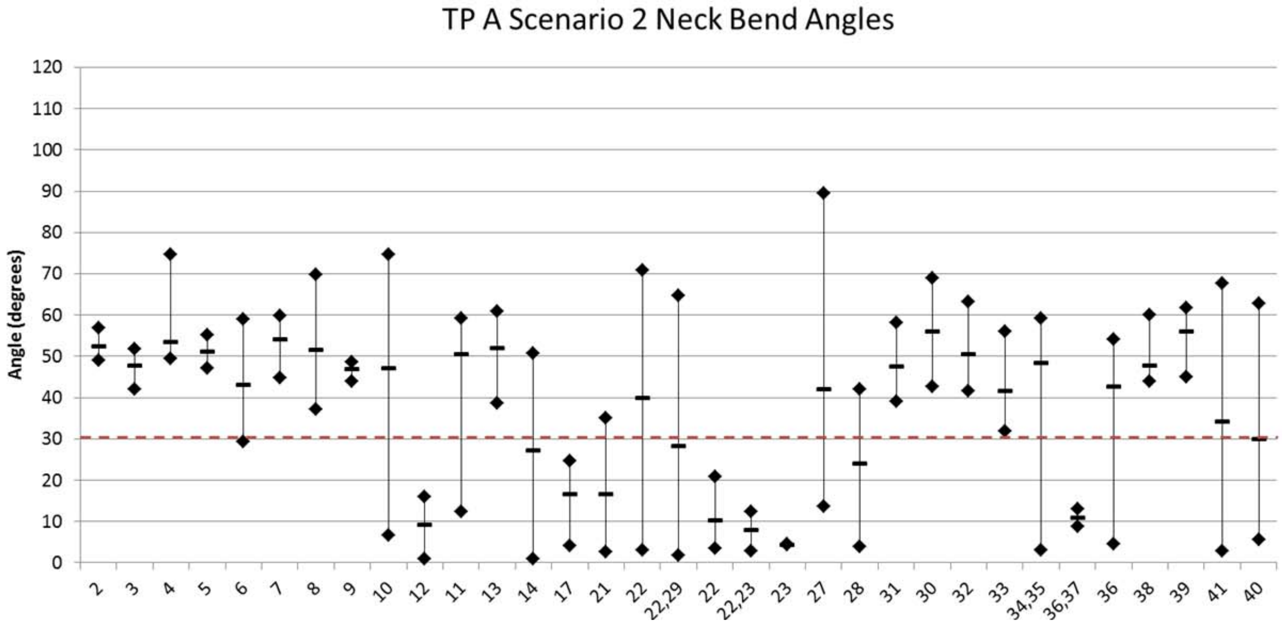


Figure D-5. TP A scenario 2 neck bend angles.

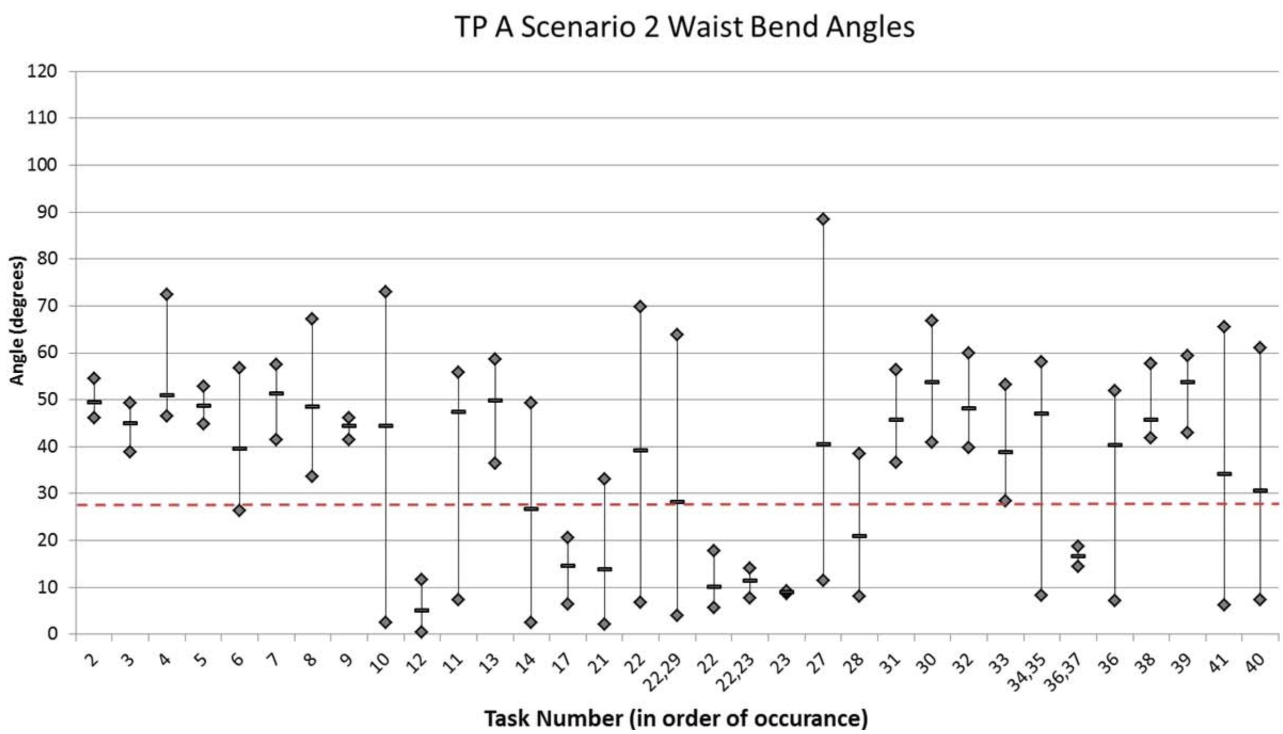


Figure D-6. TP A scenario 2 waist bend angles.

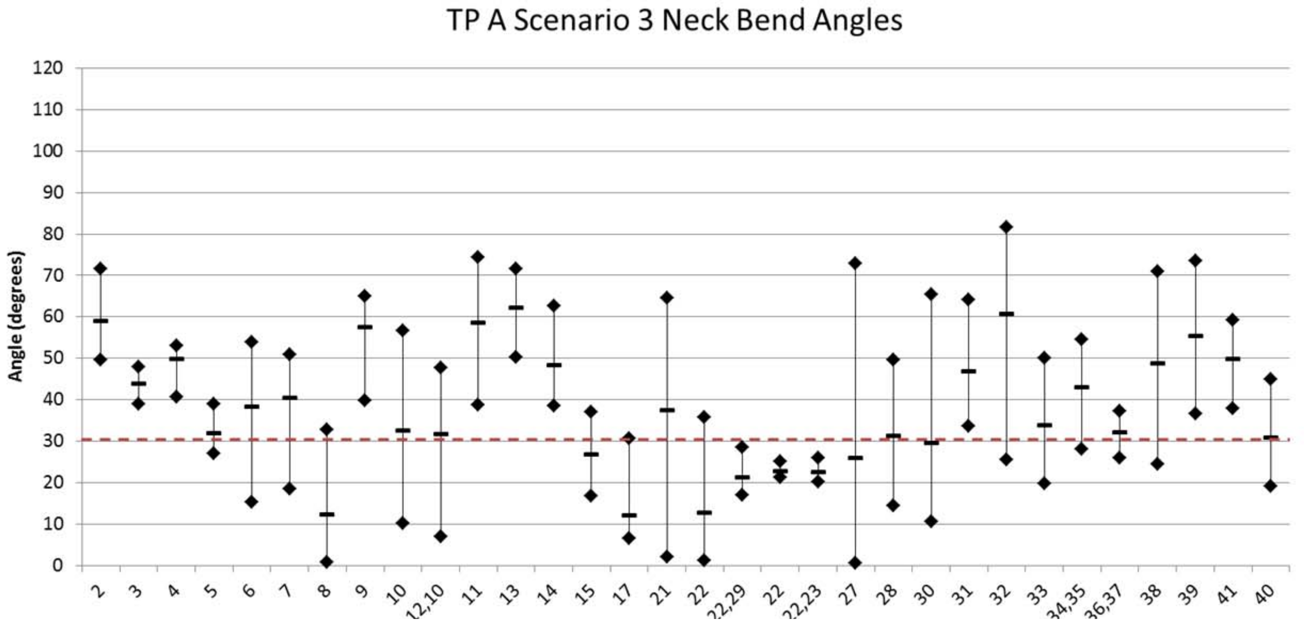


Figure D-7. TP A scenario 3 neck bend angles.

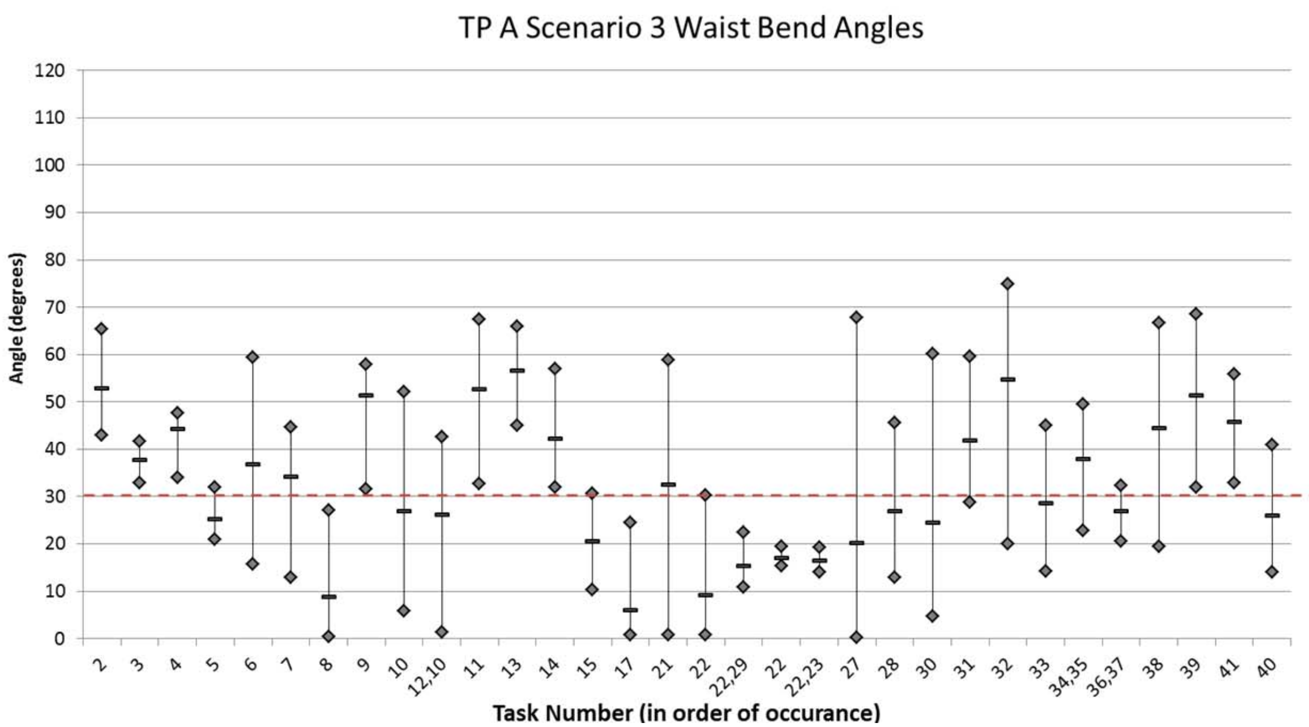


Figure D-8. TP A scenario 3 waist bend angles.

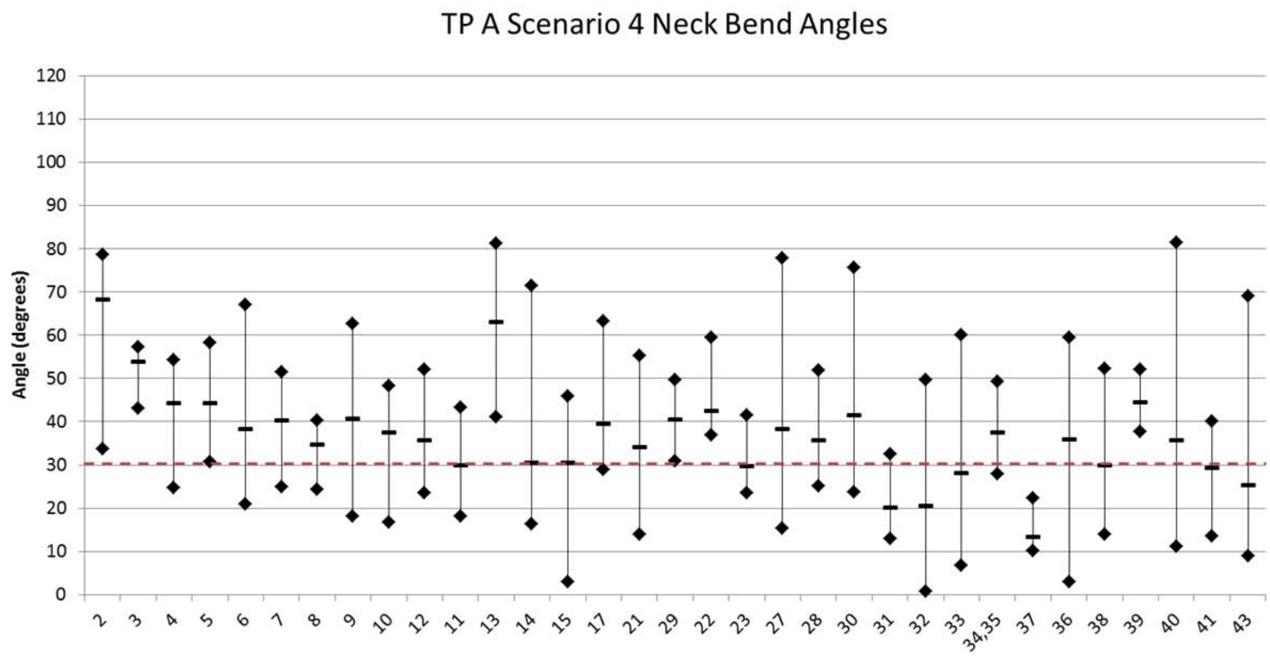


Figure D-9. TP A scenario 4 neck bend angles.

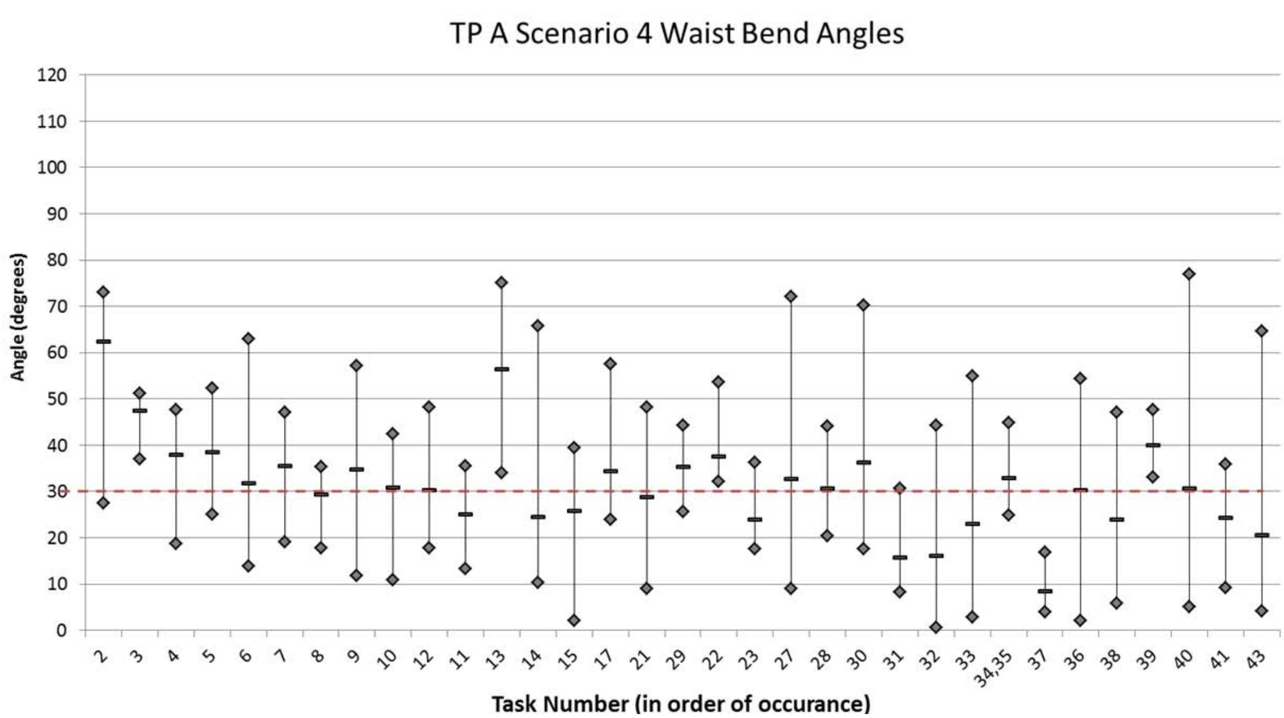


Figure D-10. TP A scenario 4 waist bend angles.

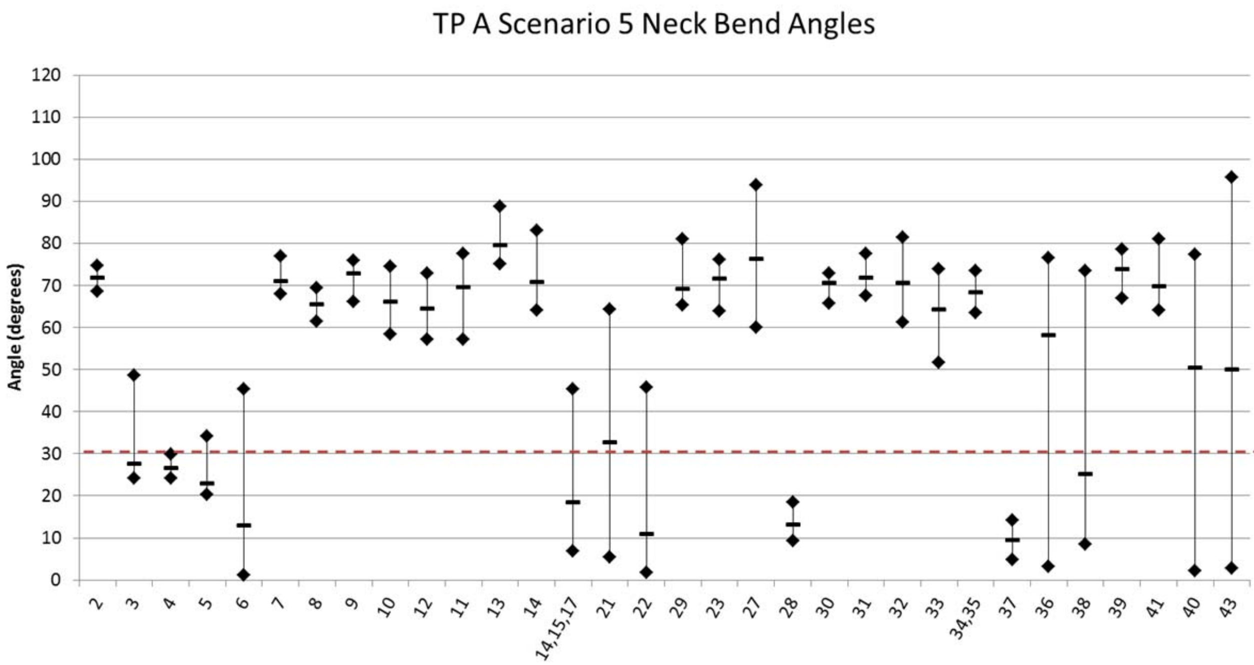


Figure D-11. TP A scenario 5 neck bend angles.

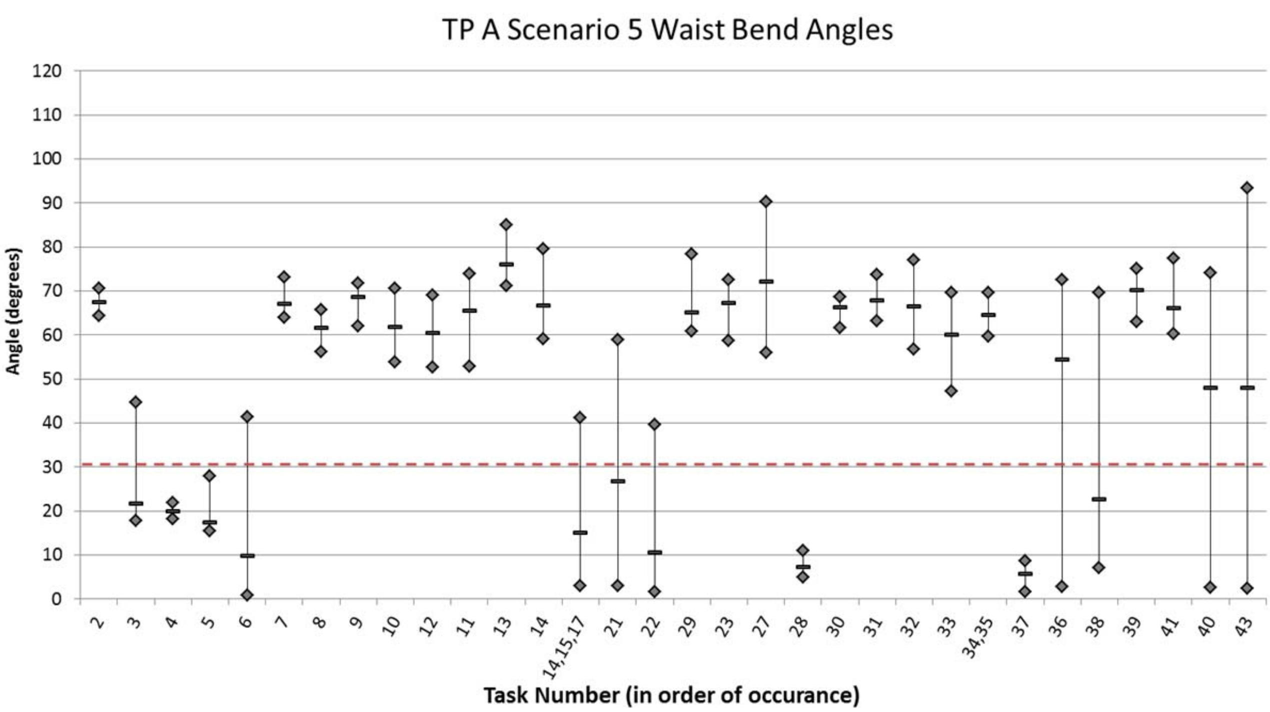


Figure D-12. TP A scenario 5 waist bend angles.

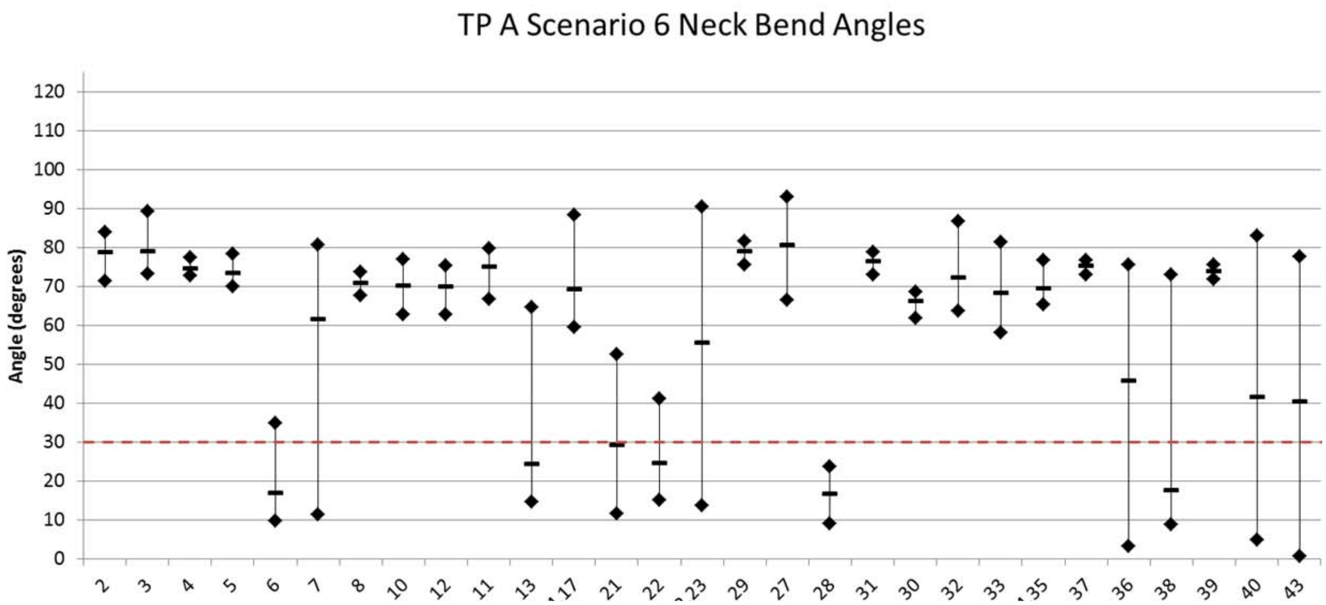


Figure D-13. TP A scenario 6 neck bend angles.

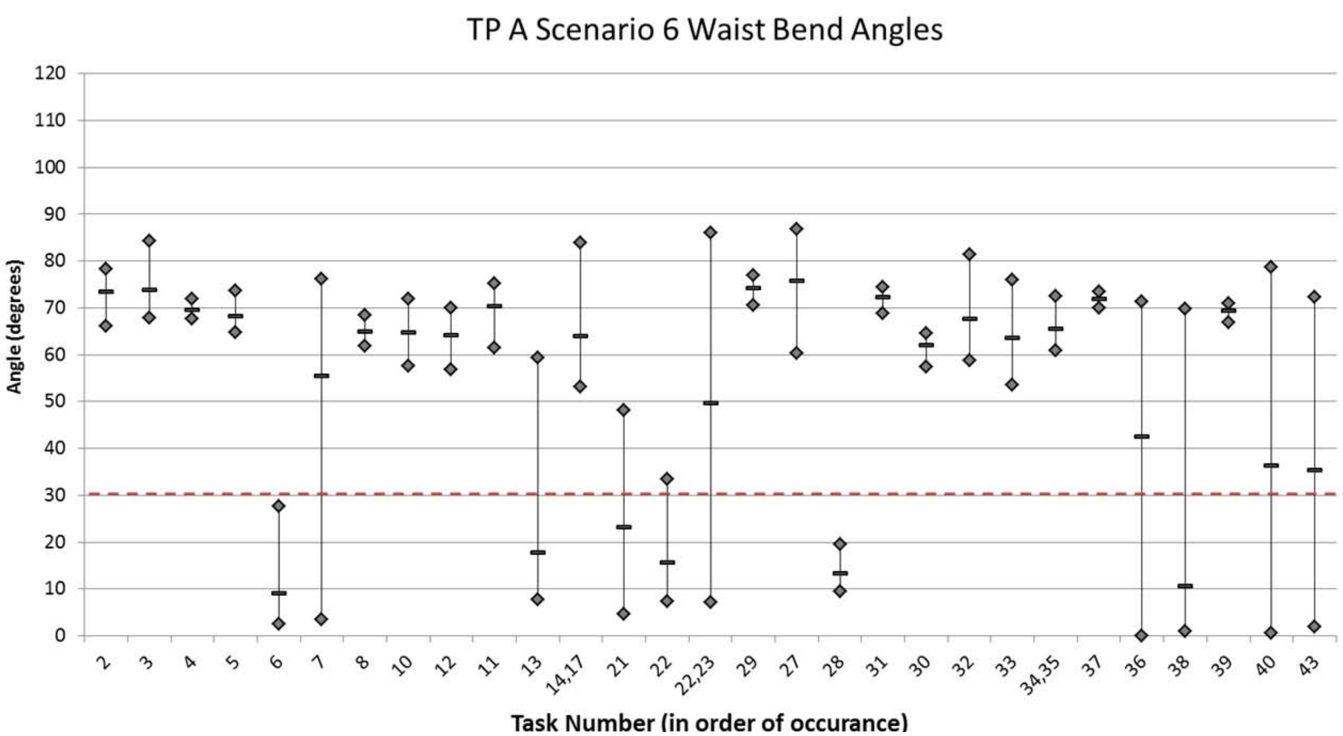


Figure D-14. TP A scenario 6 waist bend angles.

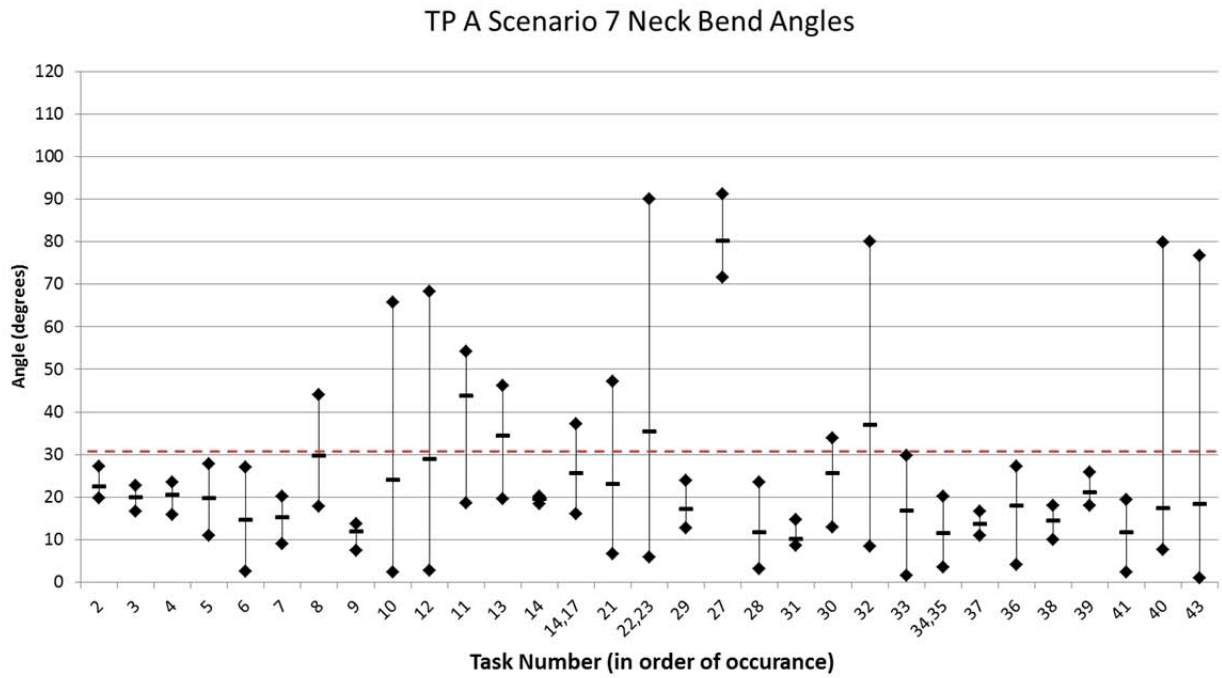


Figure D-15. TP A scenario 7 neck bend angles.

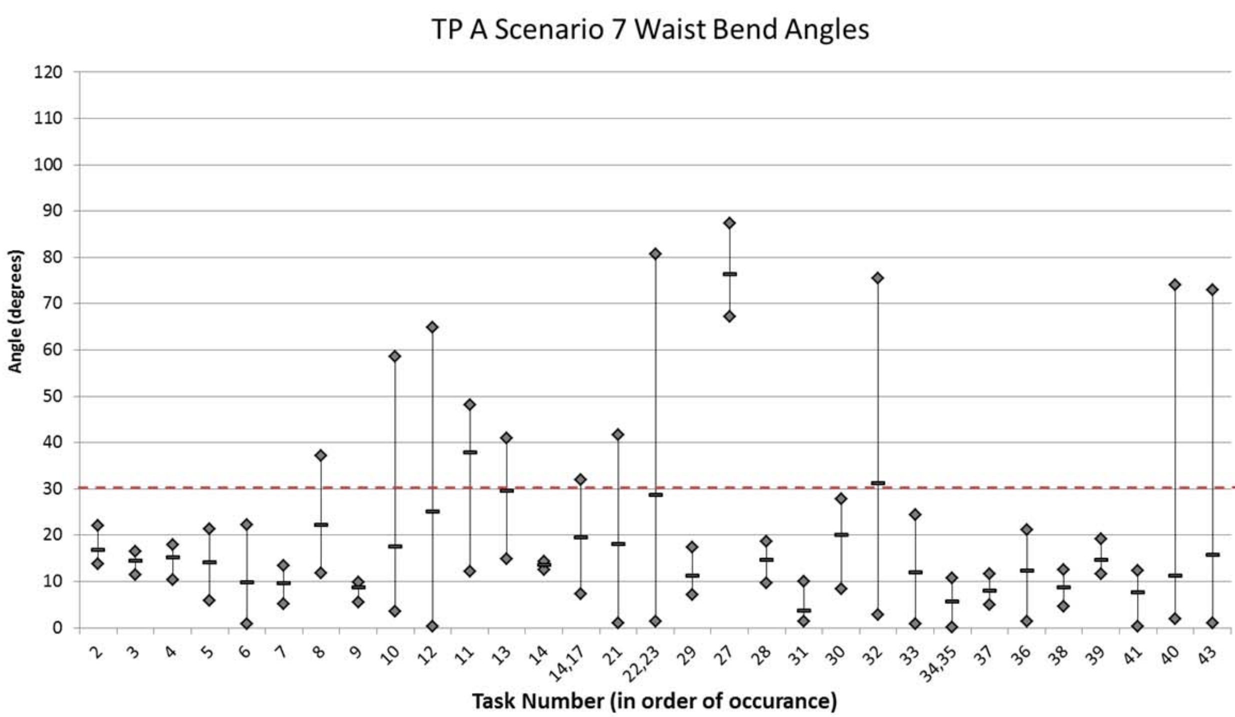


Figure D-16. TP A scenario 7 waist bend angles.

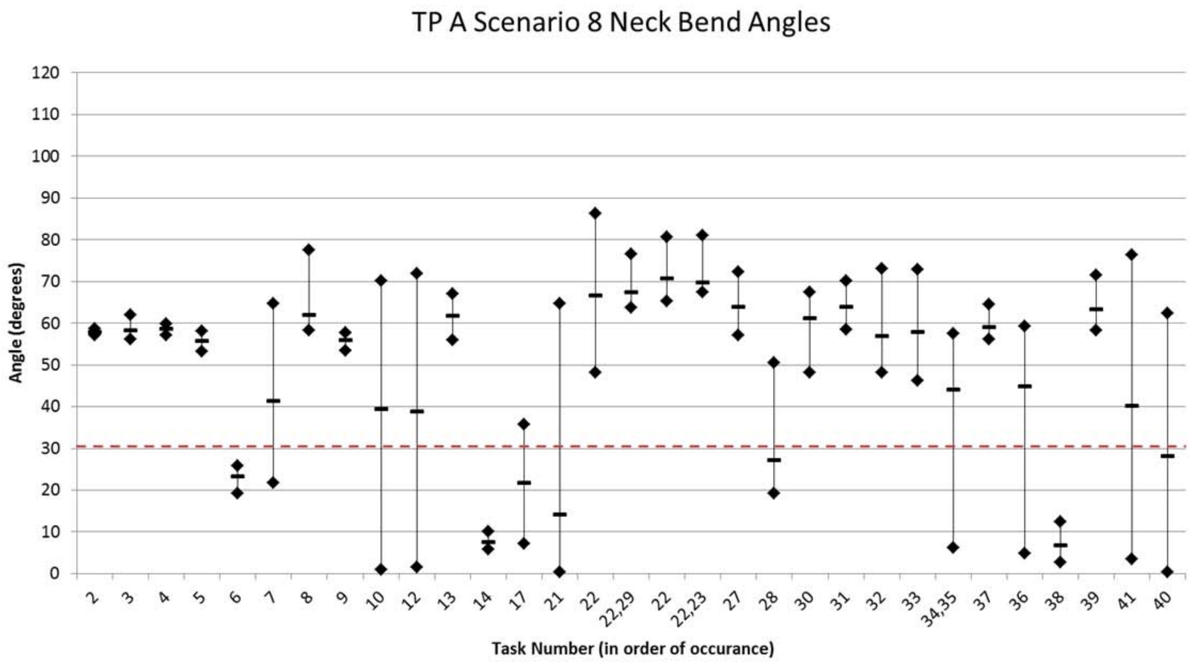


Figure D-17. TP A scenario 8 neck bend angles.

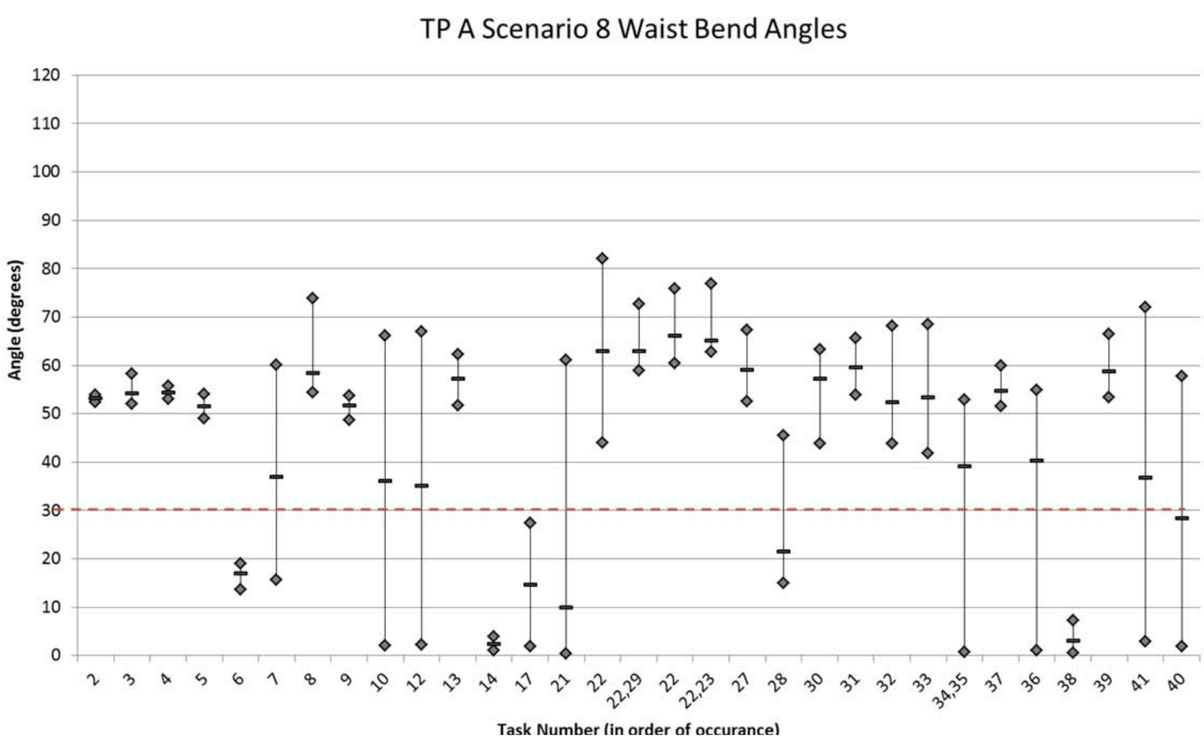


Figure D-18. TP A scenario 8 waist bend angles.

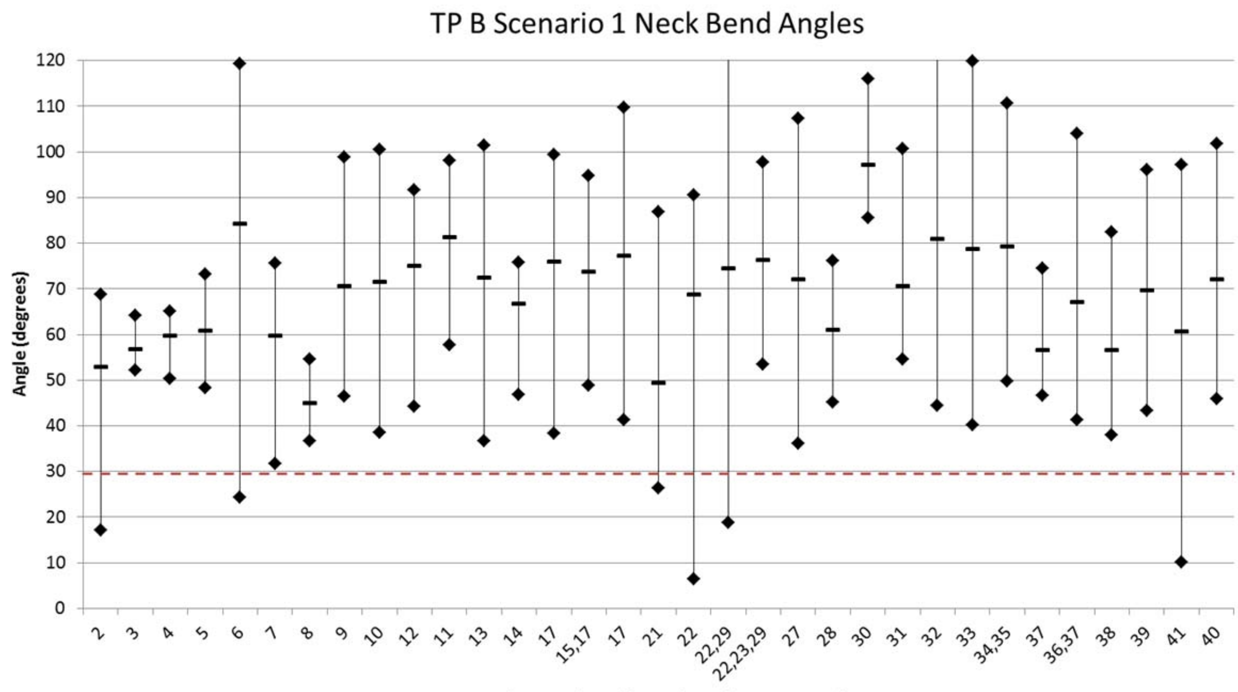


Figure D-19. TP B scenario 1 neck bend angles.

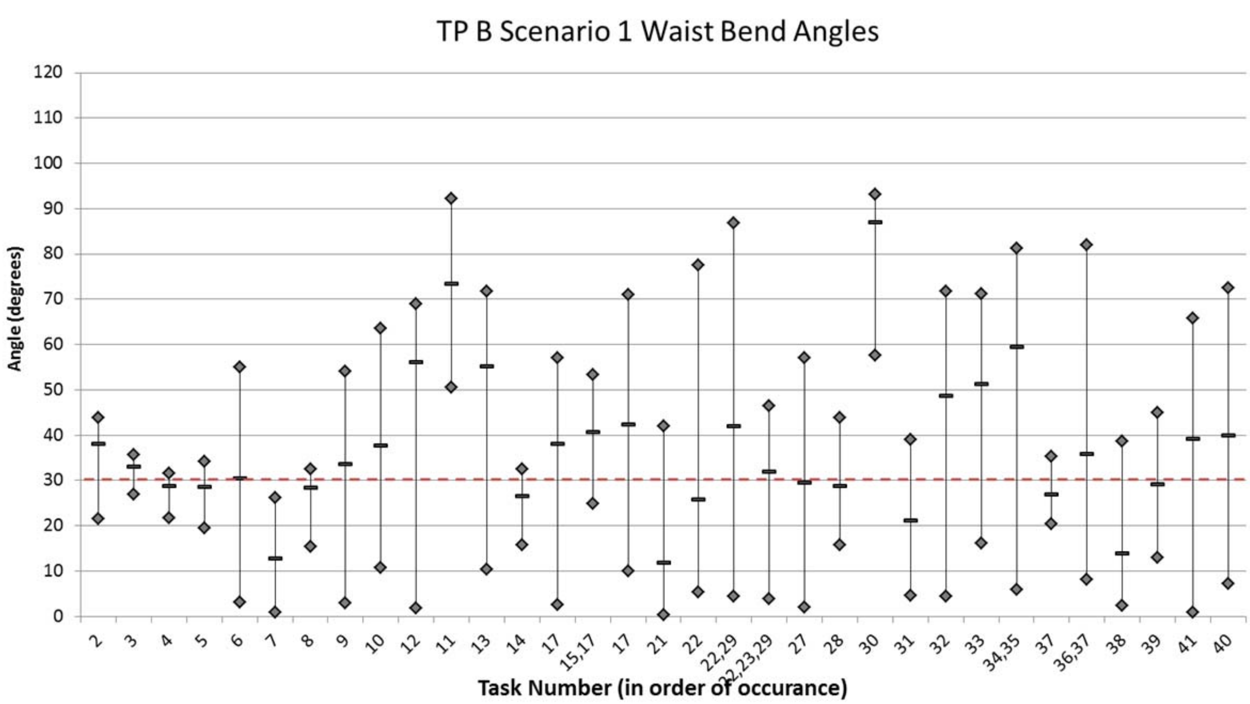


Figure D-20. TP B scenario 1 waist bend angles.

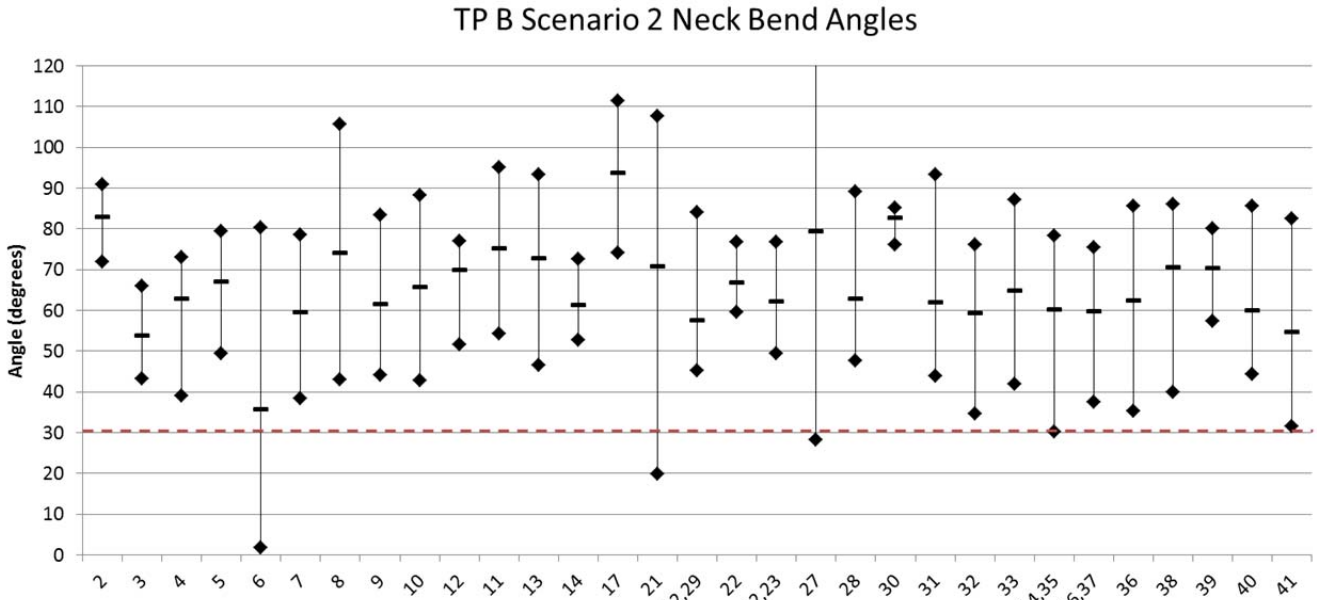


Figure D-21. TP B scenario 2 neck bend angles.

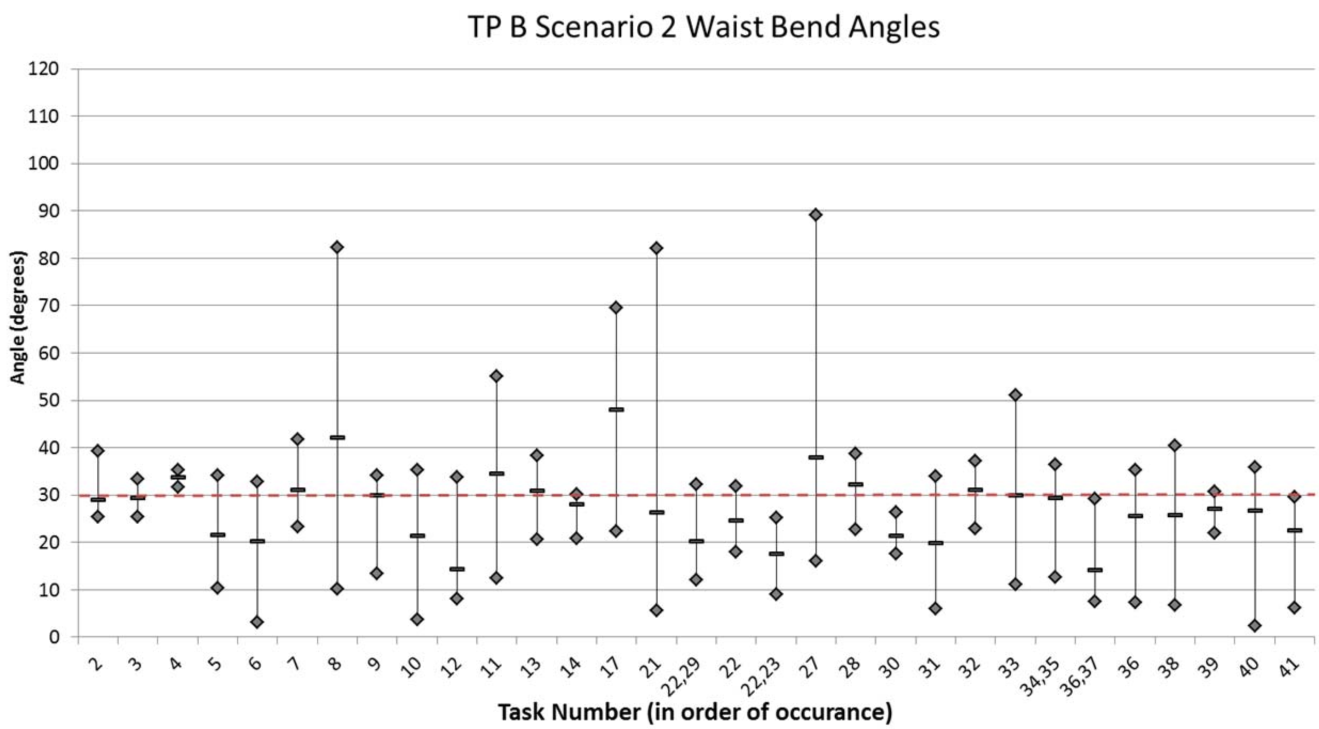


Figure D-22. TP B scenario 2 waist bend angles.

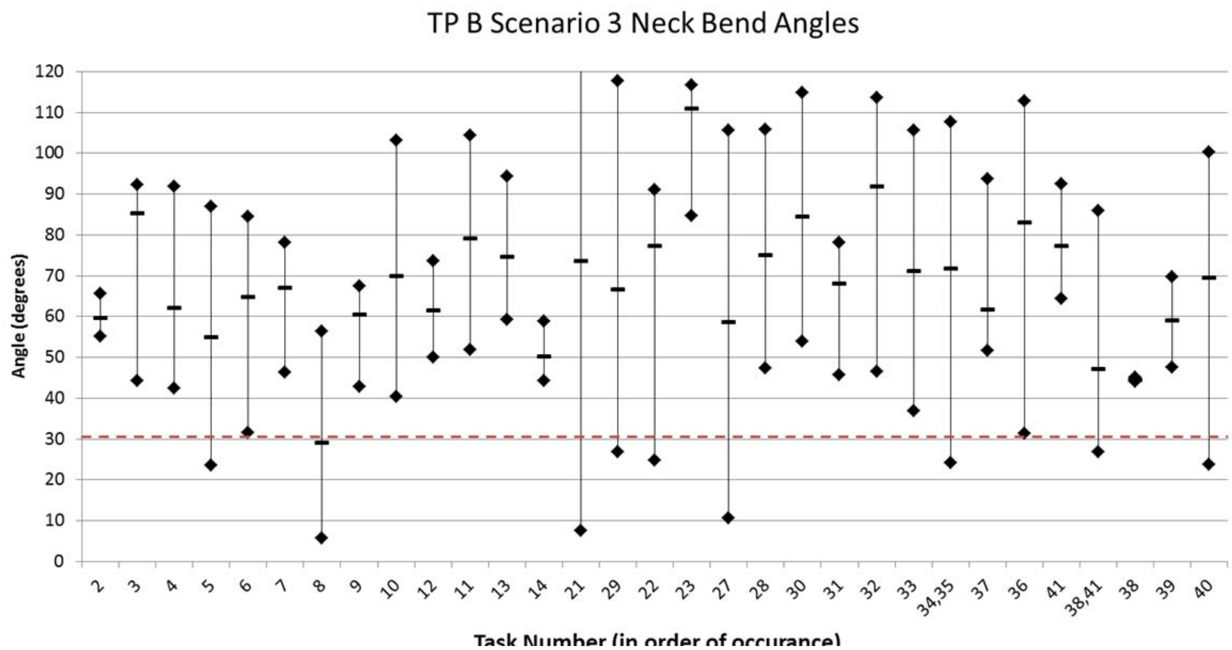


Figure D-23. TP B scenario 3 neck bend angles.

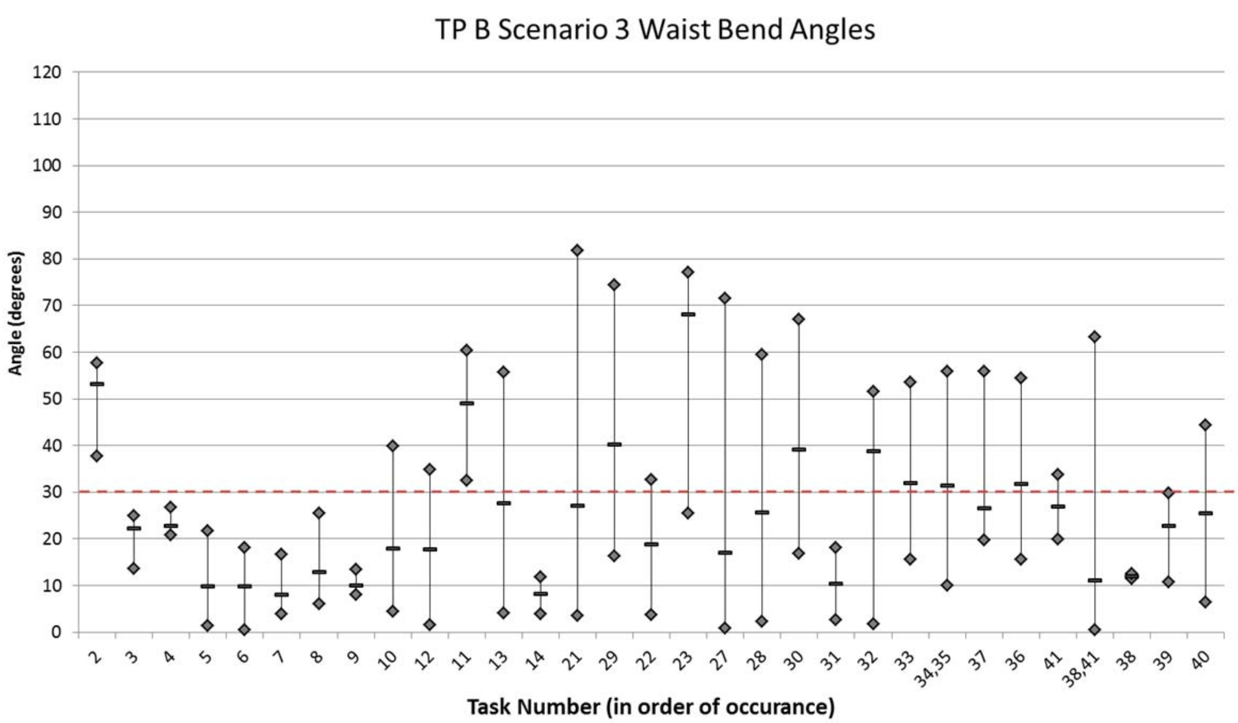


Figure D-24. TP B scenario 3 waist bend angles.

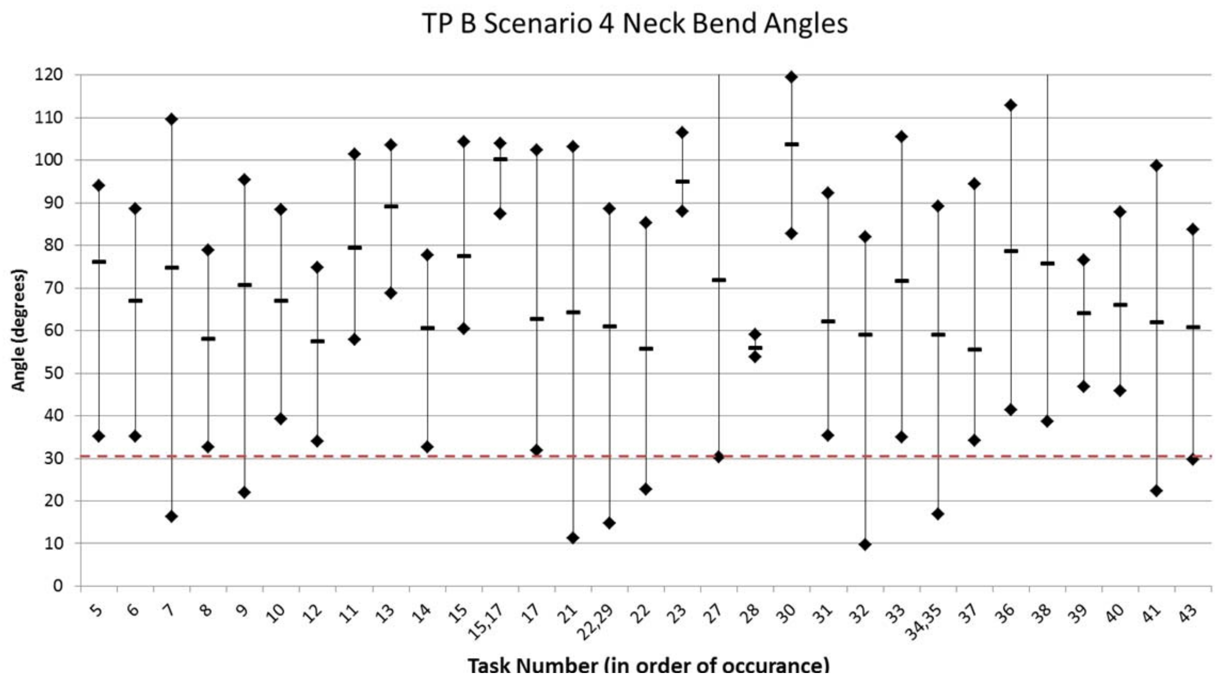


Figure D-25. TP B scenario 4 neck bend angles.

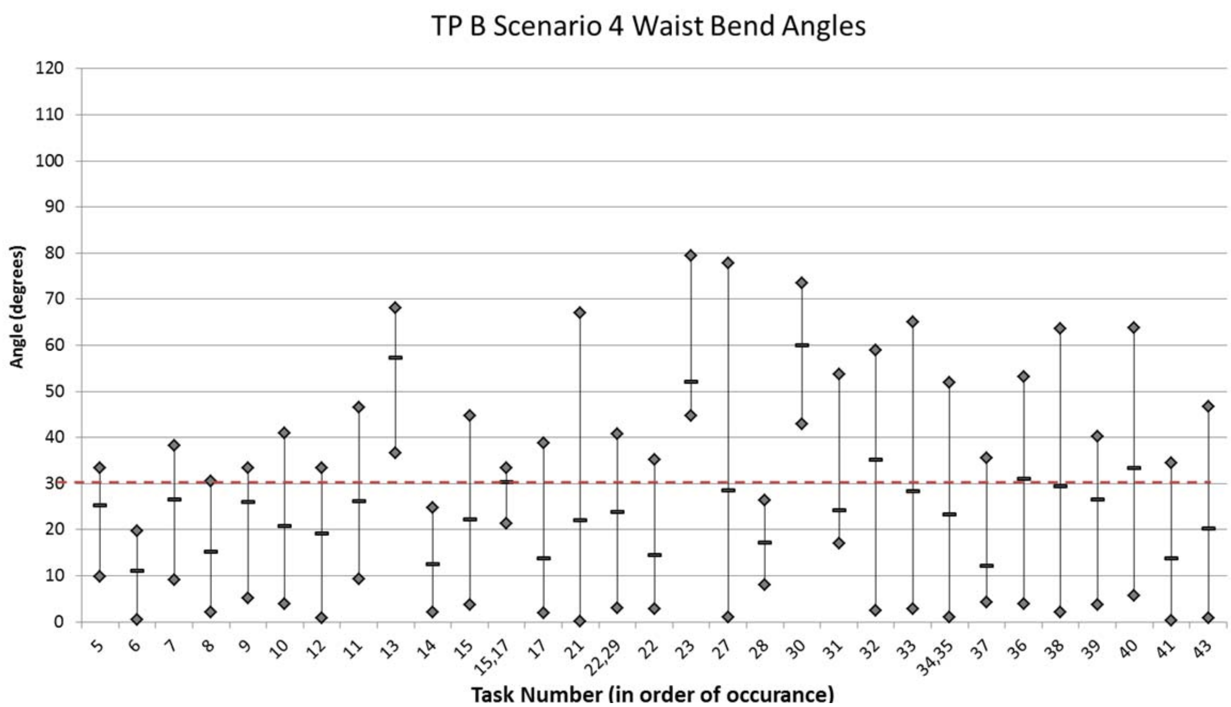


Figure D-26. TP B scenario 4 waist bend angles.

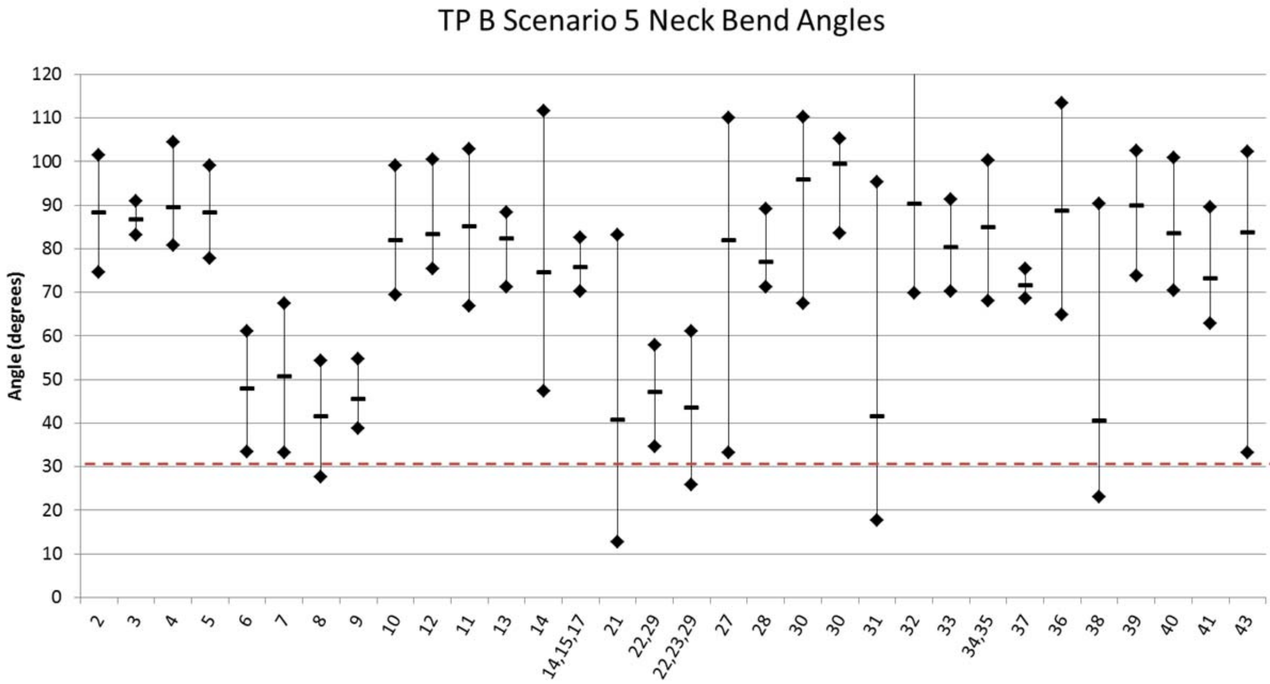


Figure D-27. TP B scenario 5 neck bend angles.

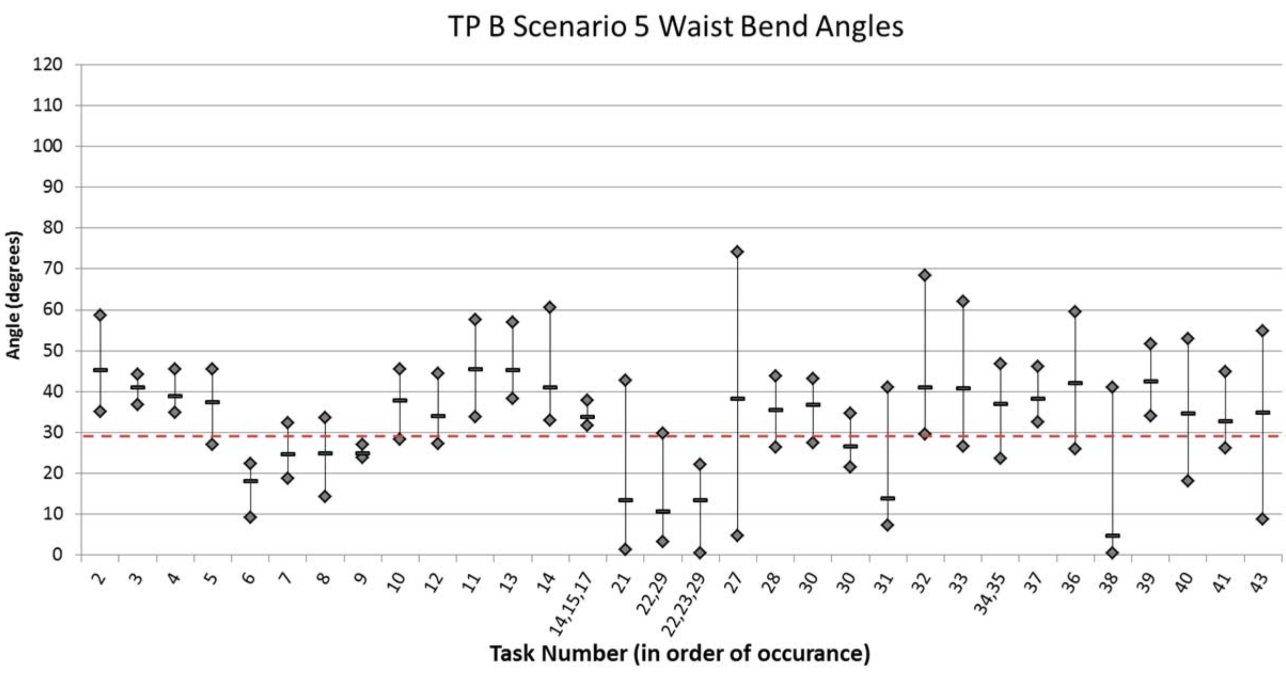


Figure D-28. TP B scenario 5 waist bend angles.

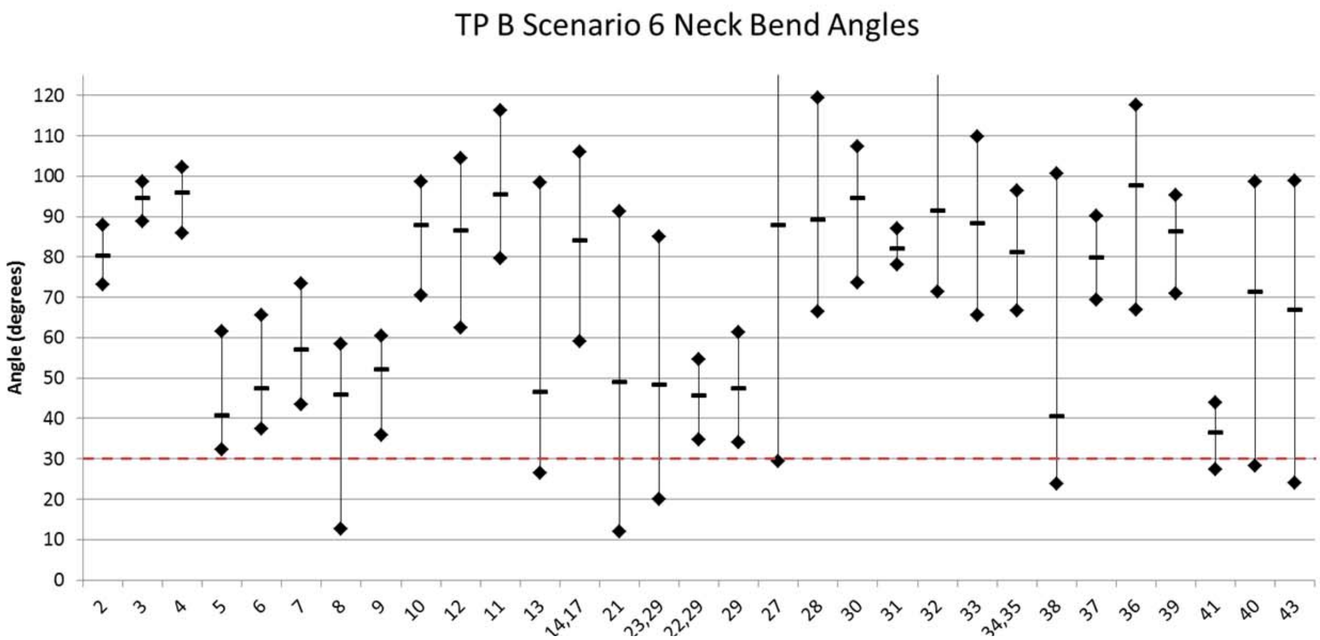


Figure D-29. TP B scenario 6 neck bend angles.

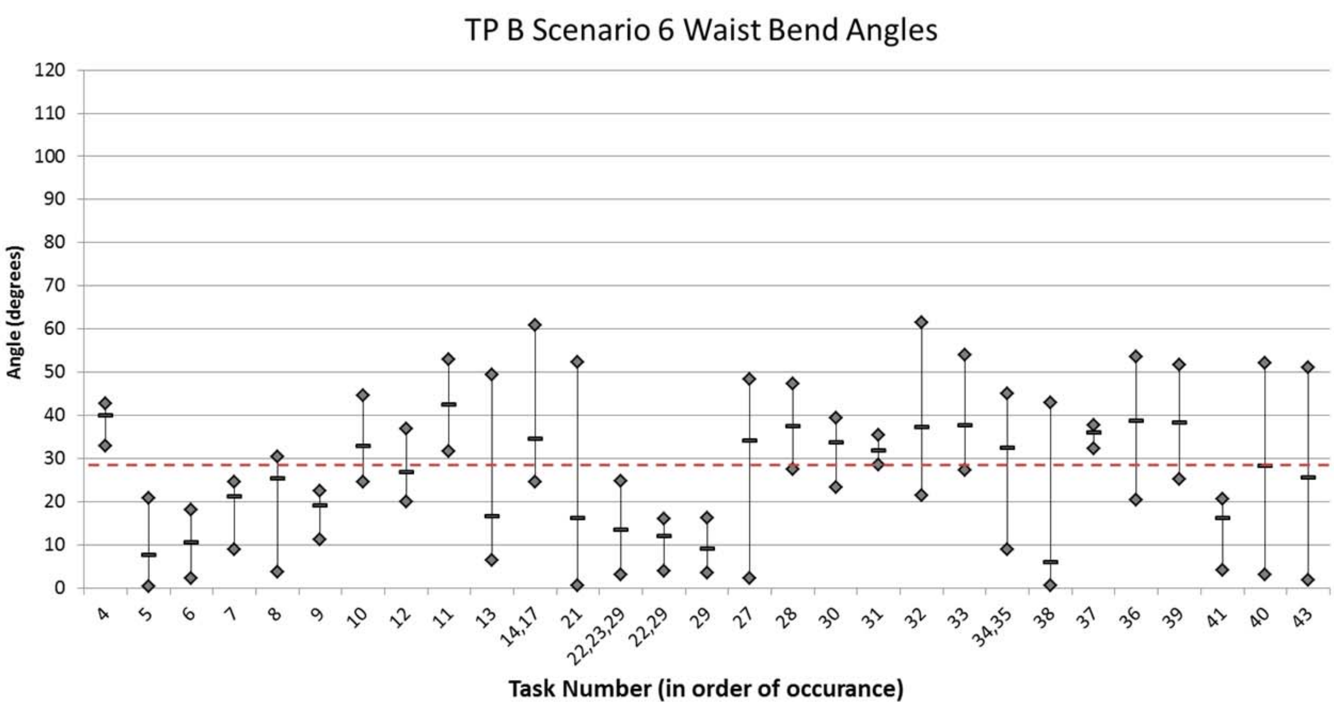


Figure D-30. TP B scenario 6 waist bend angles.

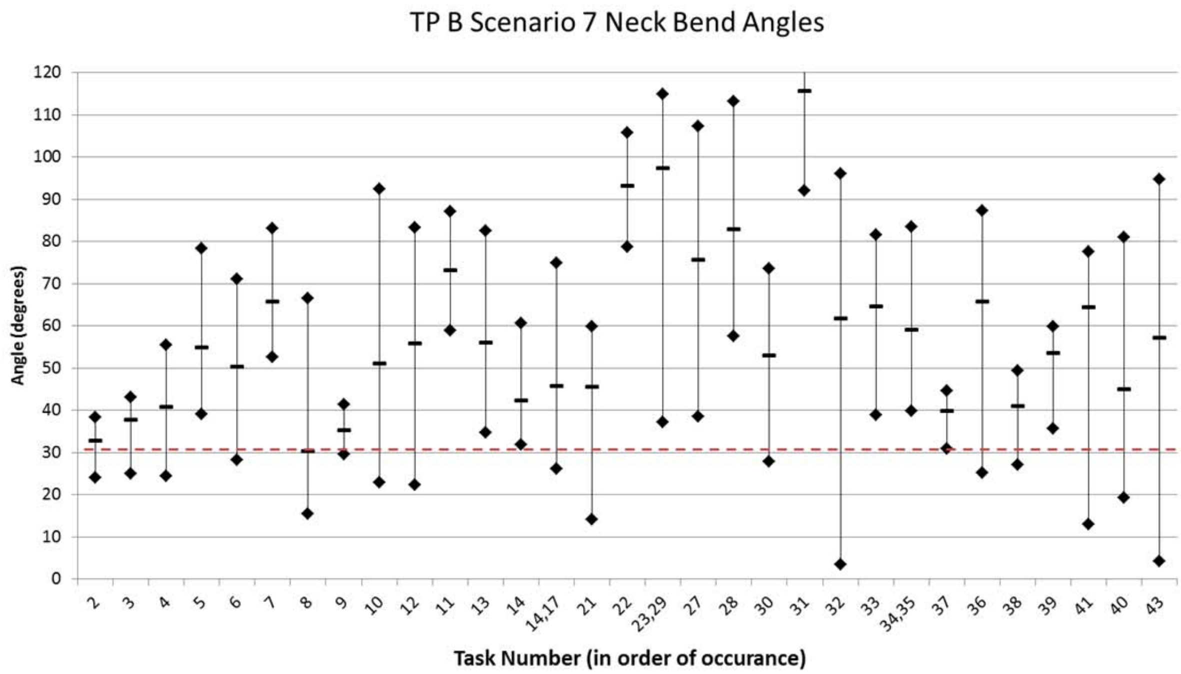


Figure D-31. TP B scenario 7 neck bend angles.

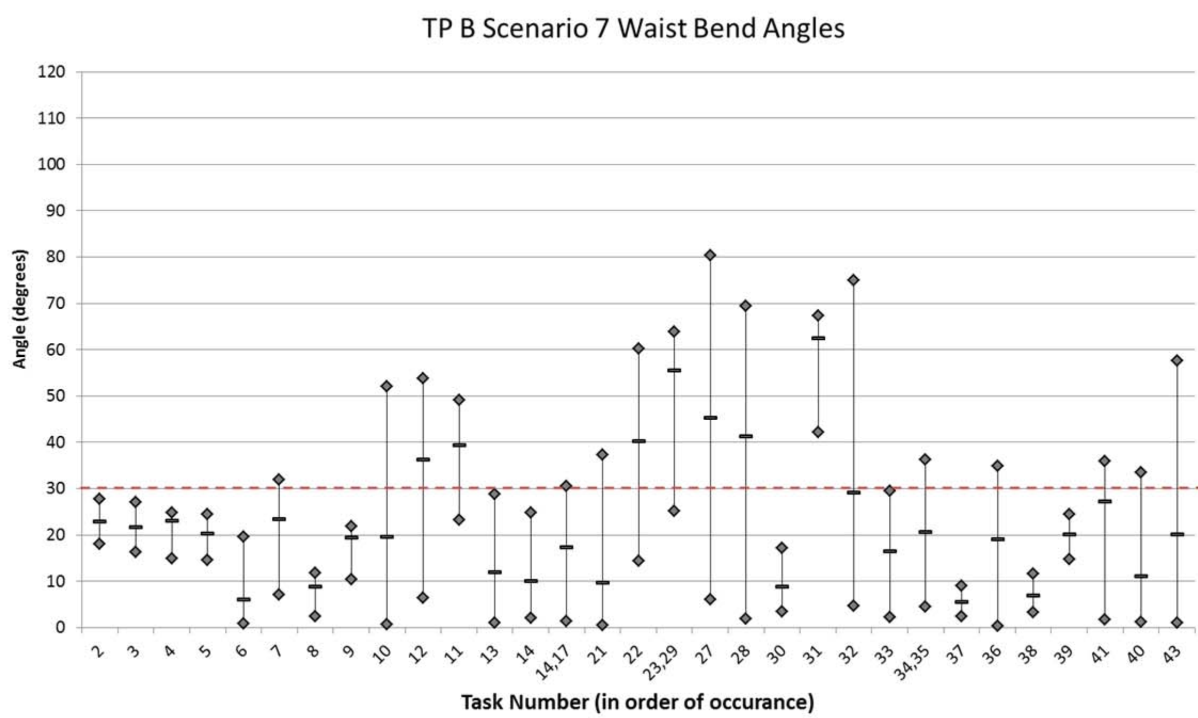


Figure D-32. TP B scenario 7 waist bend angles.

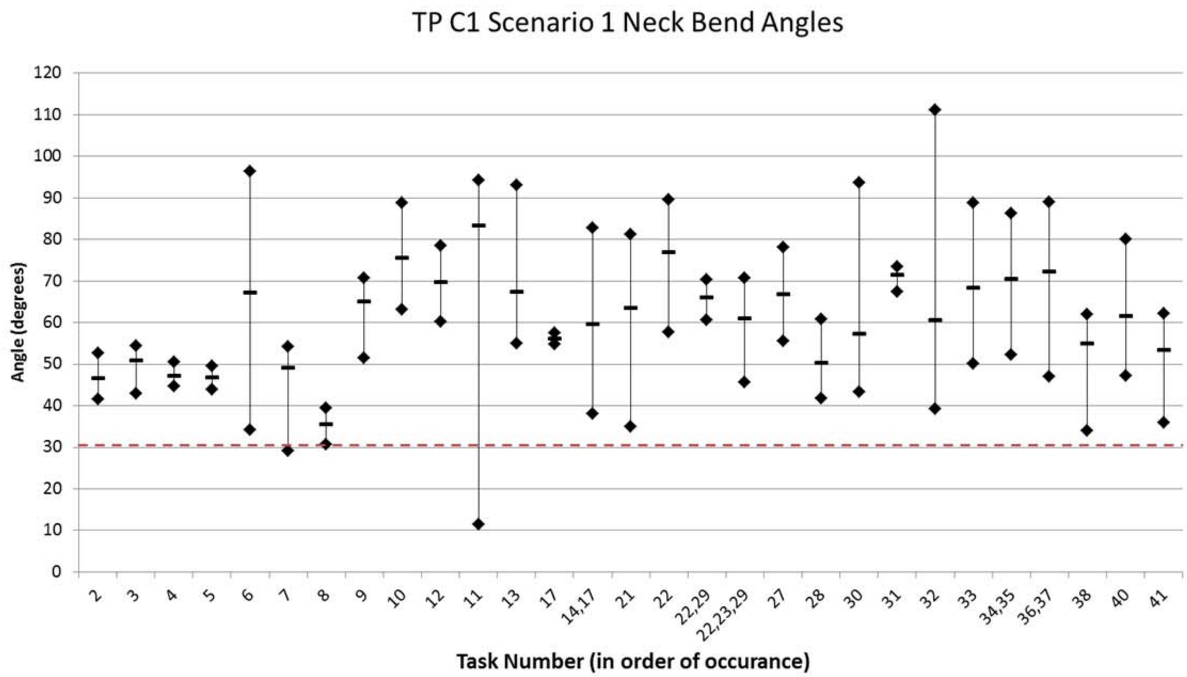


Figure D-33. TP C1 scenario 1 neck bend angles.

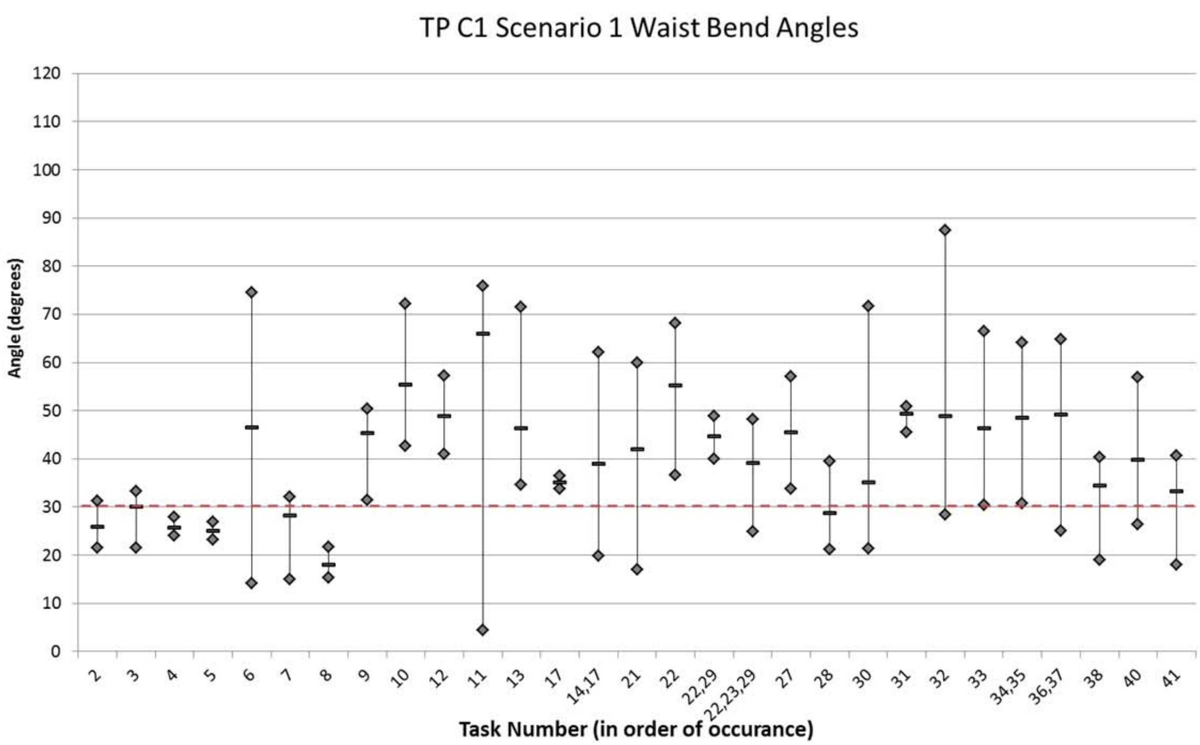


Figure D-34. TP C1 scenario 1 waist bend angles.

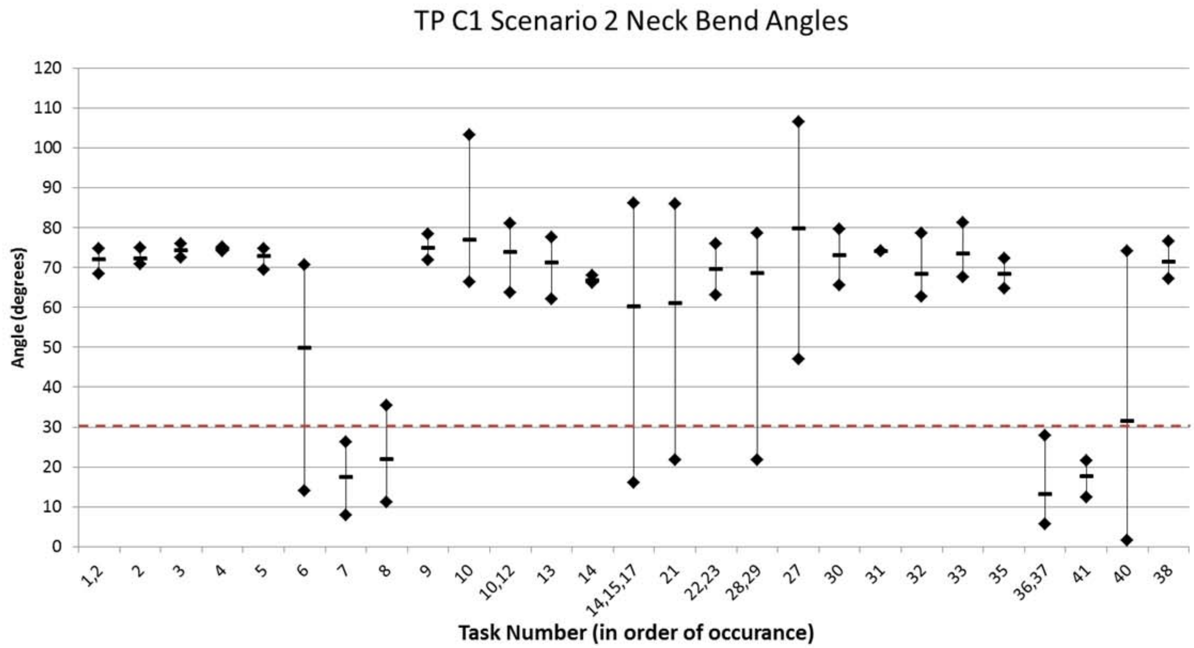


Figure D-35. TP C1 scenario 2 neck bend angles.

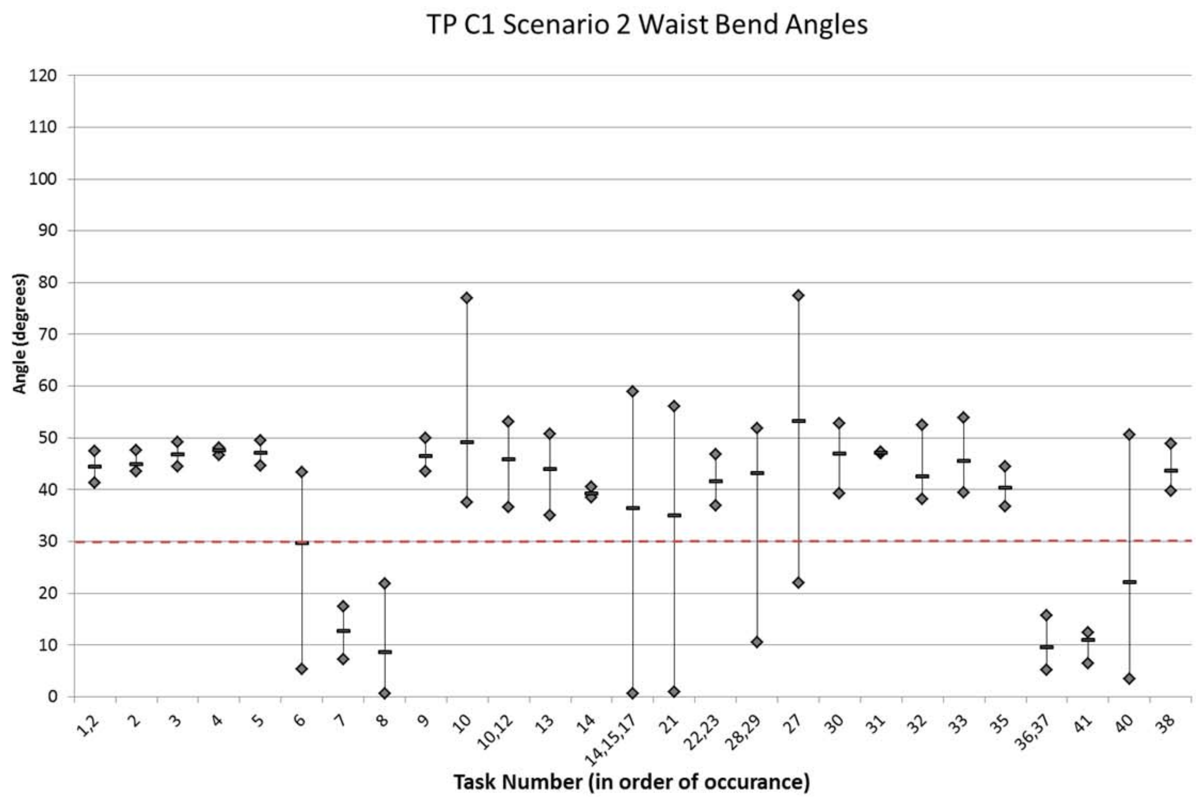


Figure D-36. TP C1 scenario 2 waist bend angles.

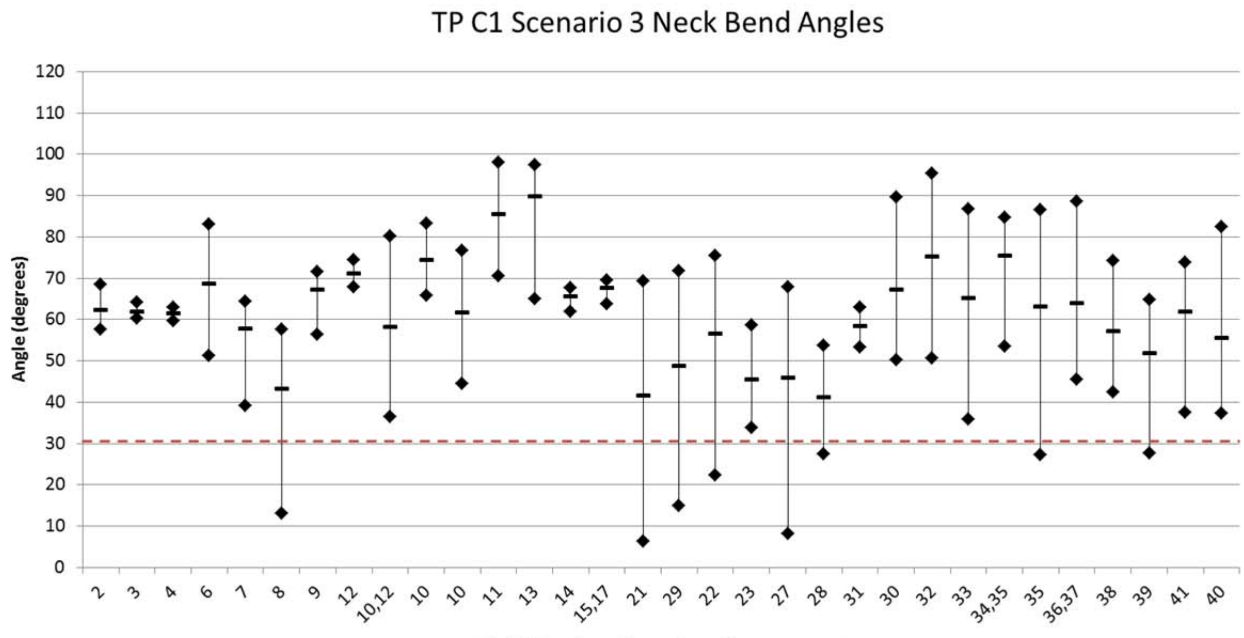


Figure D-37. TP C1 scenario 3 neck bend angles.

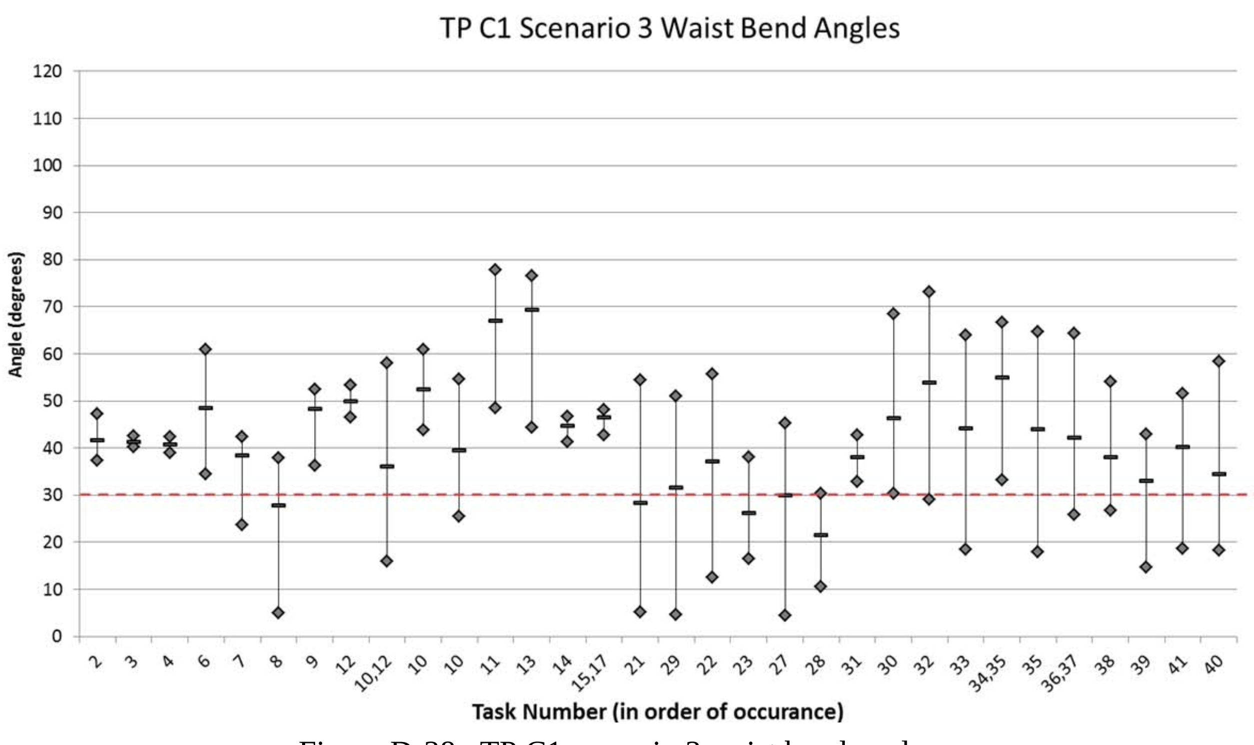


Figure D-38. TP C1 scenario 3 waist bend angles.

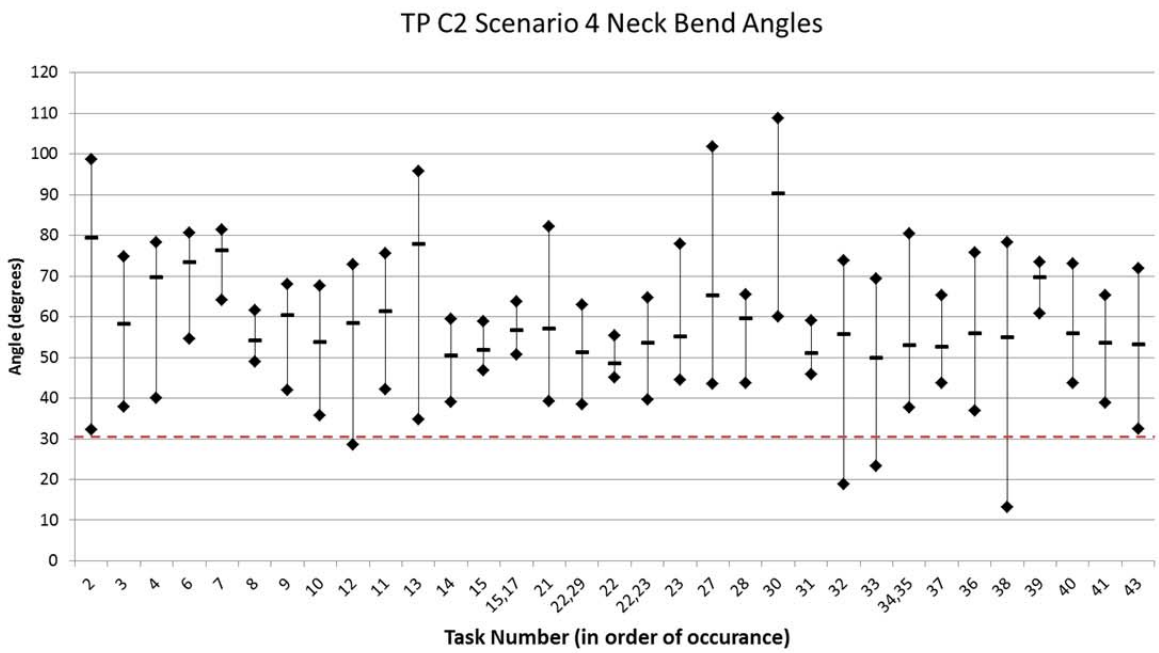


Figure D-39. TP C2 scenario 4 neck bend angles.

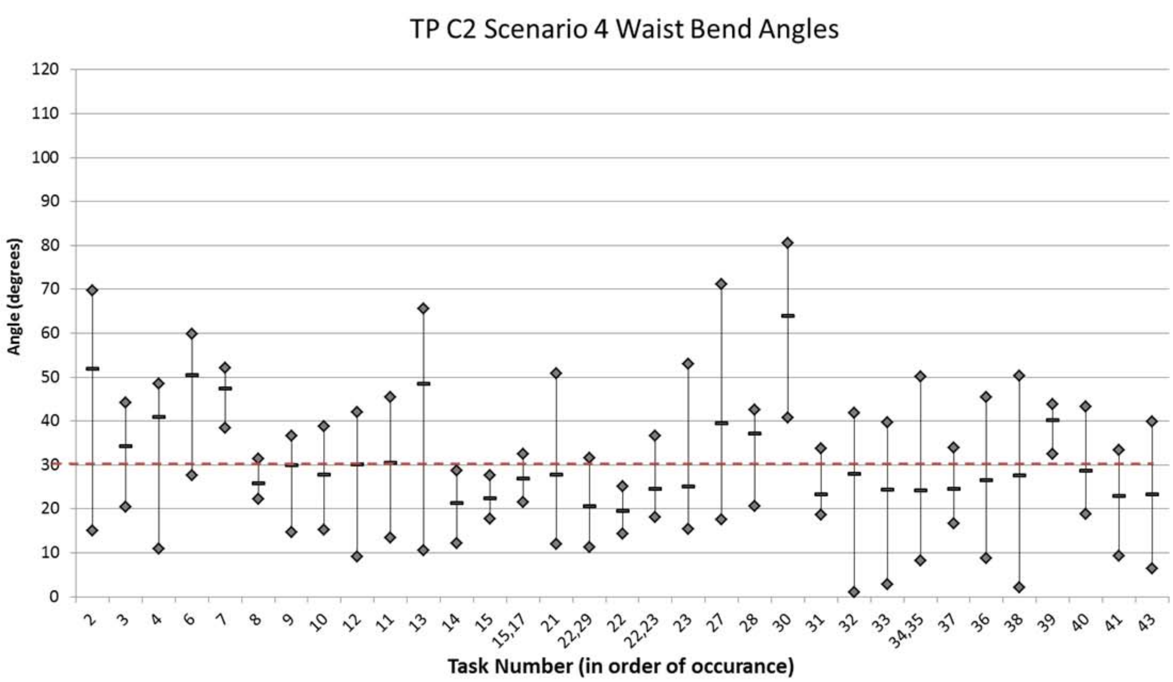


Figure D-40. TP C2 scenario 4 waist bend angles.

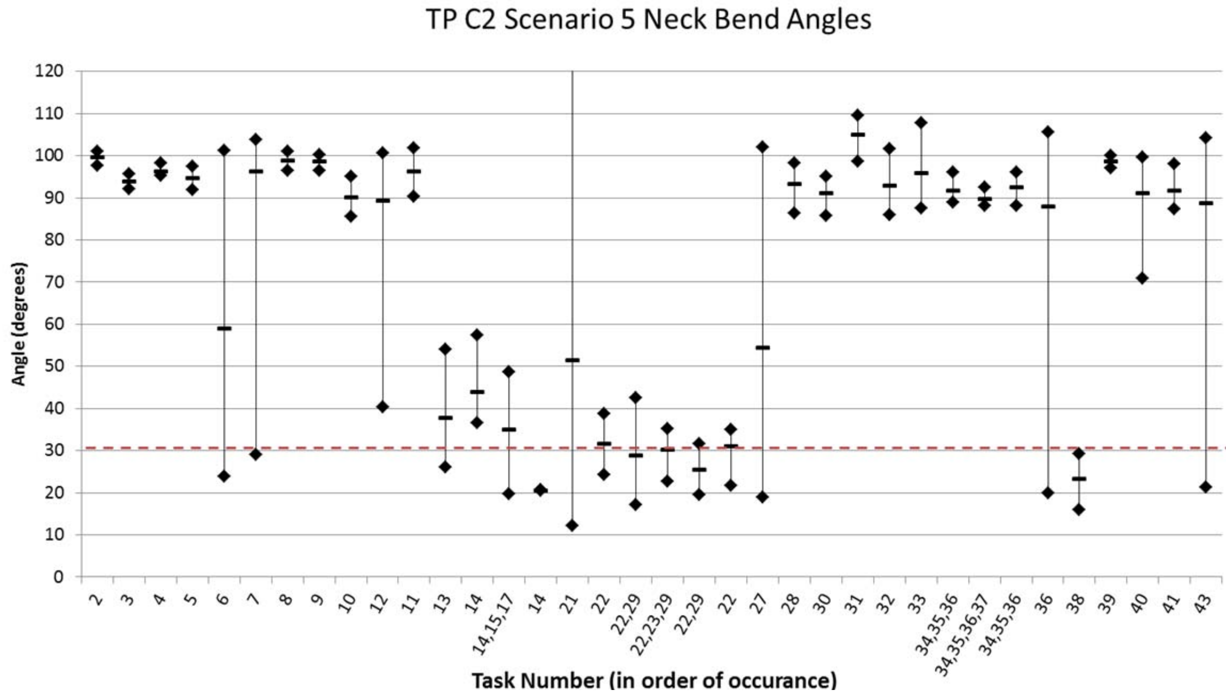


Figure D-41. TP C2 scenario 5 neck bend angles.

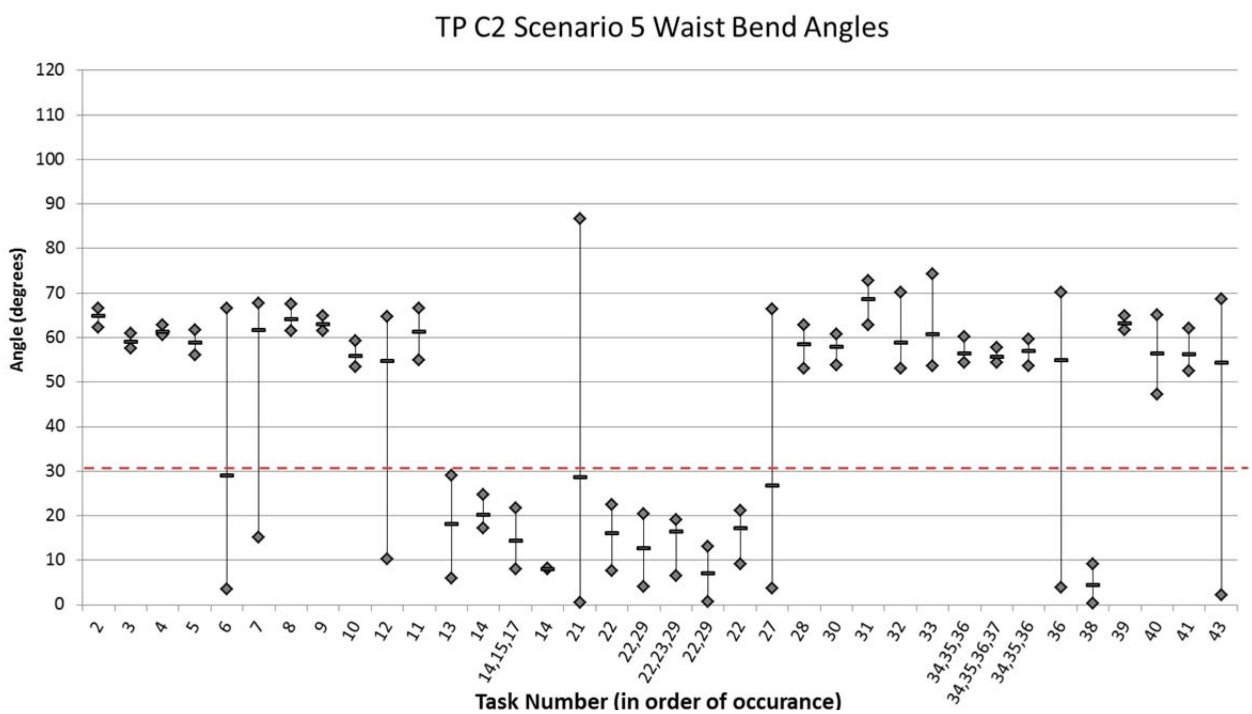


Figure D-42. TP C2 scenario 5 waist bend angles.

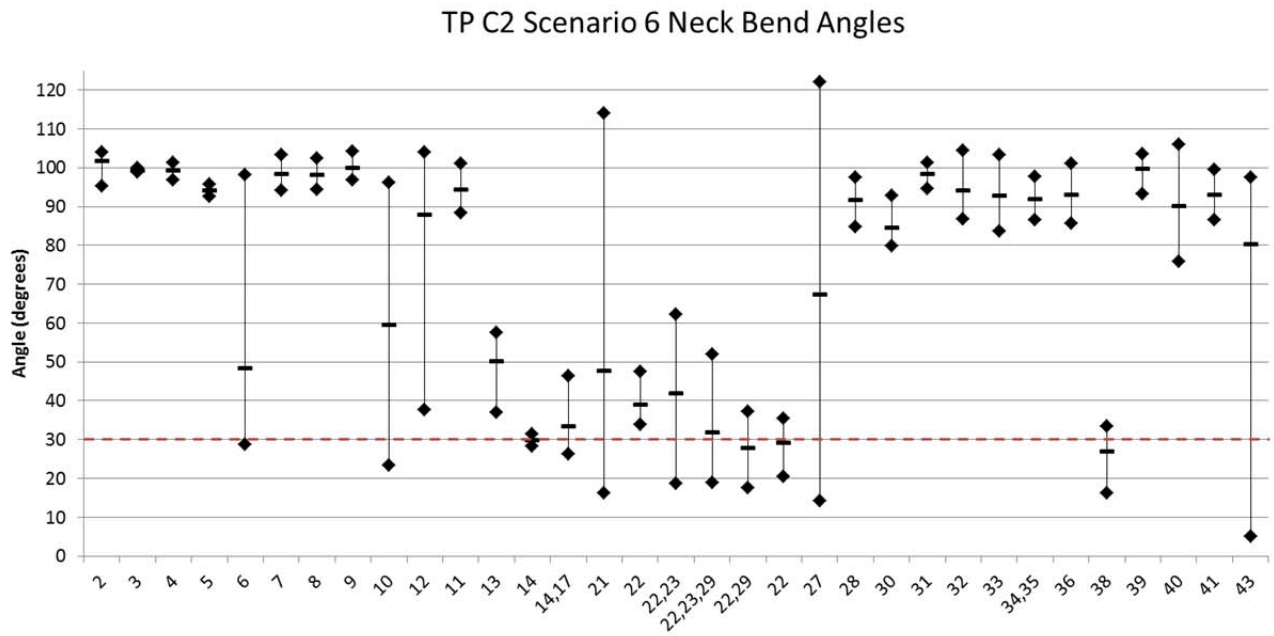


Figure D-43. TP C2 scenario 6 neck bend angles.

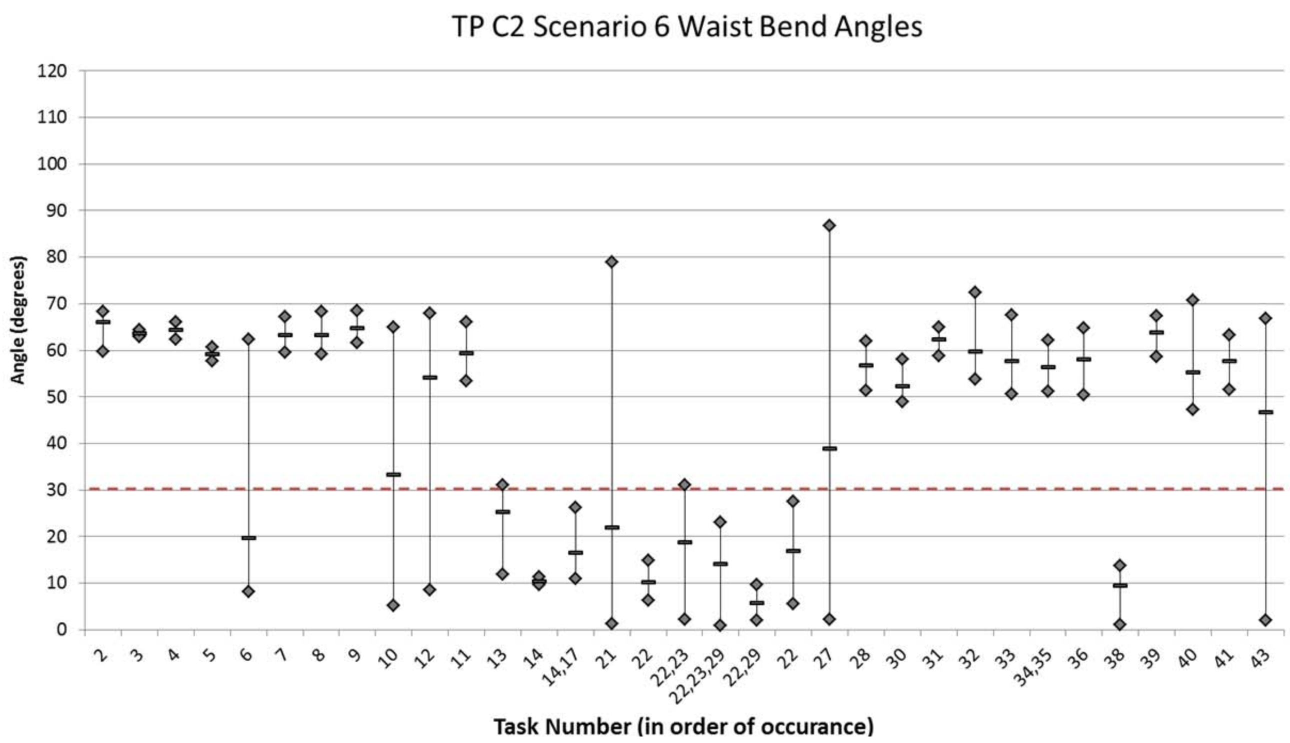


Figure D-44. TP C2 scenario 6 waist bend angles.

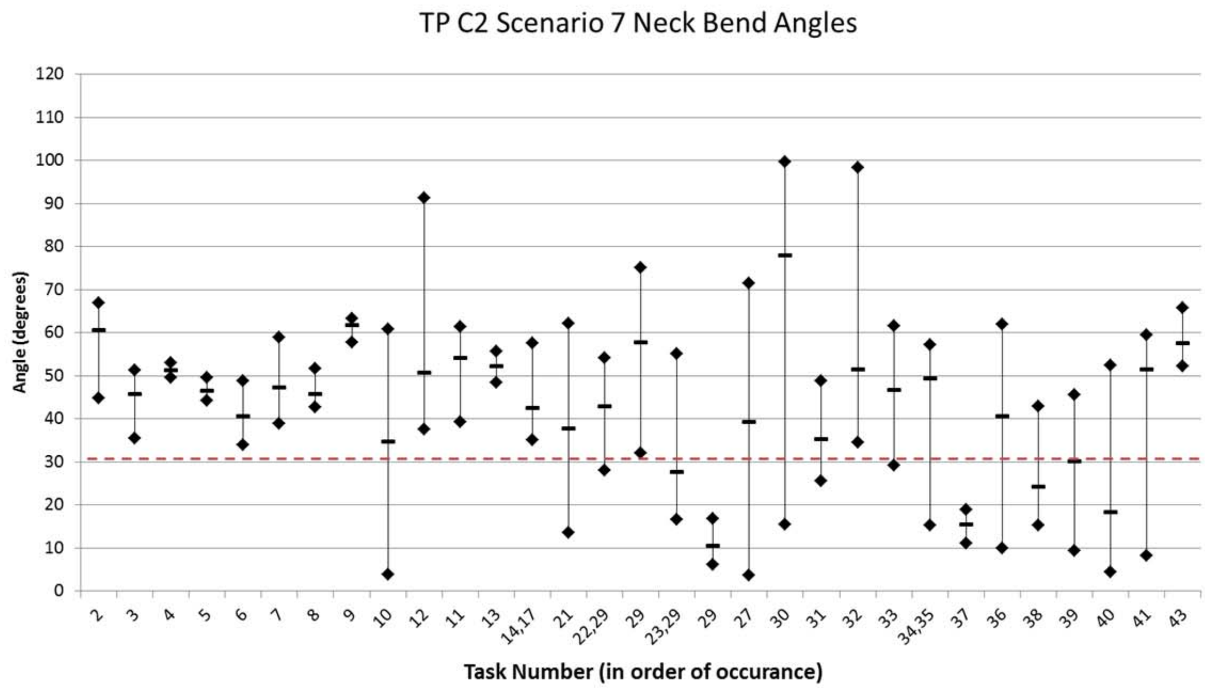


Figure D-45. TP C2 scenario 7 neck bend angles.

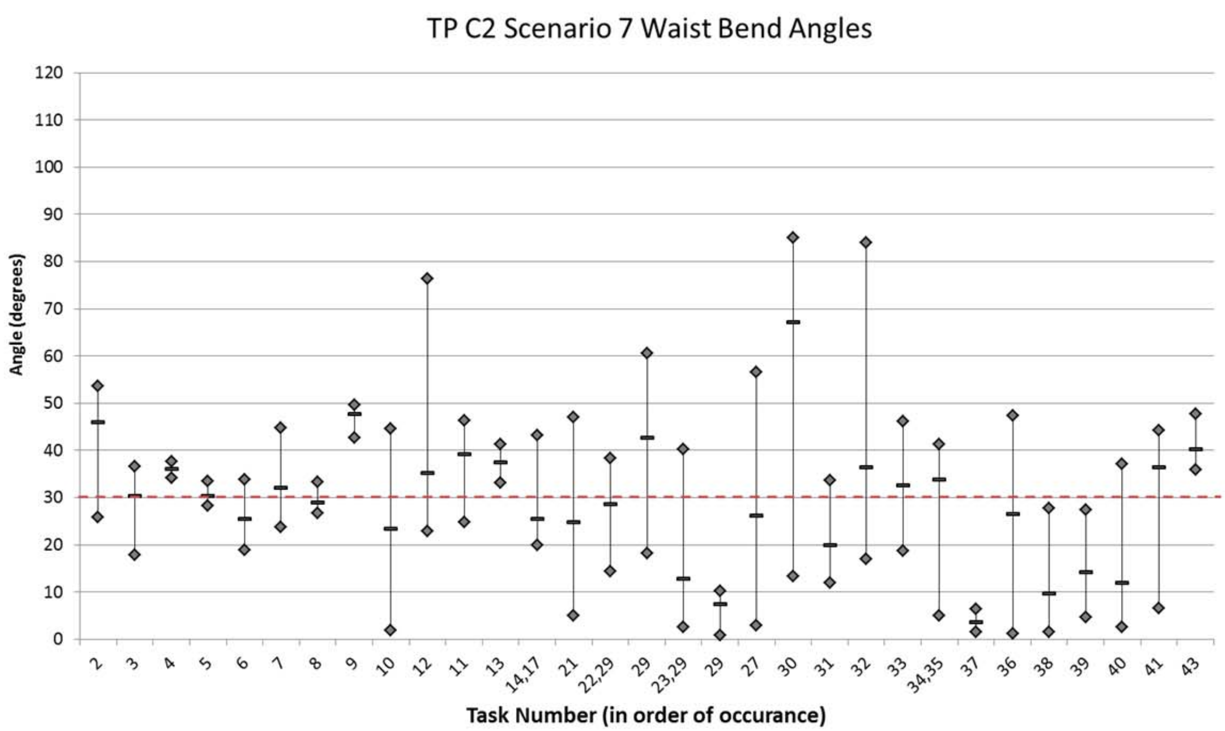


Figure D-46. TP C2 scenario 7 waist bend angles.

Appendix E.

TP post-test responses.

This page intentionally left blank.

Appendix E.

TP post-test responses.

99^{th} percentile TP – UH platform

1. Was there a task completed that required more space to be accomplished properly?
   "Yes. CPR, Direct Pressure, FAST"
2. Was there a task required to complete that was unable to be performed due to the space available when treating the patient?
   "Yes. CPR, Direct pressure, FAST. Height non-conducive to asses or treat far end injuries."
3. Were there any tasks that were completed that were done in an improper position (e.g., not positioned above head to perform intubation)?
   "Yes. FAST"
4. Additional comments:
   "Had to maintain a squatting position entire time"

99^{th} percentile TP – HH-60 platform

1. Was there a task completed that required more space to accomplish properly?
   "No"
2. Was there a task required to complete that was unable to be performed due to the space available when treating the patient?
   "CPR"
3. Were there any tasks that were completed that were done in an improper position? (i.e. not positioned above head to perform intubation.
   "No"
4. Additional comments:
   "Difficult to turn around in 6 patient configuration. I was able to lean over patient, better for assessment/treatment. Also, less stress on legs and back."

2nd percentile TP – UH-60 platform

1. Was there a task completed that required more space to be accomplished properly?

   "Intubation, tourniquet"

2. Was there a task required to complete that was unable to be performed due to the space available when treating the patient?

   "CPR, traction splint"

3. Were there any tasks that were completed that were done in an improper position? (e.g., not positioned above head to perform intubation.

   "Not positioned properly to do CPR, intubation, defibrillation, FAST1"

4. Additional comments:

   "None"

2nd percentile TP – UH-60 platform

1. Was there a task completed that required more space to accomplish properly?

   "CPR, FAST, traction, direct pressure, arm fracture"

2. Was there a task required to complete that was unable to be performed due to the space available when treating the patient?

   "CPR, FAST, direct pressure, chest tube"

3. Were there any tasks completed that were done in an improper position? (e.g., not positioned above head to perform intubation.

   "Intubation, abdominal evisceration dressing, Reel Splint Immobilizer,™ chest tube"

4. Additional comments:

   "A lot of strain on back when working on upper litters due to angle of body"

80th percentile TP – UH-60 platform

1. Was there a task completed that required more space to accomplish properly?

   "Any task that was conducted on the outbound side of the patient.

   I was able to apply a TQ but was not effective.

   Performing chest compressions was not possible.

   FAST 1"

2. Was there a task required to complete that was unable to be performed due to the space available when treating the patient?

   "Just about all tasks. The effectiveness was negatively impacted."

3. Were there any tasks that were completed that were done in an improper position? (e.g., not positioned above head to perform intubation.

   "IV access on outbound side."

4. Additional comments:

   "Deck load patients!!!"

   Change doctrine, 6 patients on an A/C equals dead patients."

75th percentile TP – HH-60 platform

1. Was there a task completed that required more space to accomplish properly?

   "CPR, Reel Splint Immobilizer™, arm FX, chest tube"

2. Was there a task required to complete that was unable to be performed due to the space available when treating the patient?

   "CPR"

3. Were there any tasks that were completed that were done in an improper position? (e.g., not positioned above head to perform intubation.

   "Fast 1"

4. Additional comments:

   "In the 1 patient and 2 patient scenario, extra strain on back and upper legs to reach appropriate angle without compromising PT"

This page intentionally left blank.

Appendix F.

Phase 3 test results.

This page intentionally left blank.

Appendix F.

Phase 3 test results.

Table F-1.
Differences in results for 24 in. vertical spacing in upper and lower litter position.

Consolidated bottom Litter @ 24 inches	TP 1	TP 2	TP 3	TP 4	TP 5	TP 6	TP 7	TP 8	TP 9	TP 10	TP 11	TP 12	TP 13	TP 14	TP 15
Task 1: Load casualties into helicopter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 2: Open the airway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 3: Insert an oropharyngeal airway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 4: Insert a nasopharyngeal airway	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 5: Insert a King LT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 6: Intubate a patient	0	1	0	0	1	0	1	0	1	0	0	0	0	0	0
Task 7: Perform a surgical cricothyroidotomy	0	0	0	1	2	1	0	2	2	0	0	0	0	0	0
Task 8: Perform endotracheal suctioning of a patient	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Task 9: Perform a needle chest decompression	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Task 10: Treat a casualty with a chest injury	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 12: Administer initial treatment for burns	0	1*	0	0	0	1*	0	0	0	0	0	0	0	0	0
Task 13: Perform rescue breathing	0	2	1	1	2	1	0	0	0	1	0	1	0	0	0
Task 14: Ventilate a patient with bag-valve-mask system	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 15: Set up a D-sized oxygen tank	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 17: Administer oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 18: Measure a patient's pulse oxygen saturation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 19: Measure a patient's blood pressure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 20: Operate the Propaq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 21: Operate the Zoll	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 22: Operate the Alaris IV pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 23: Operate the IV fluid warmer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 25: Measure a patient's pulse	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 26: Measure a patient's temperature	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 27: Perform advanced cardiac life support	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Task 28: Initiate treatment for hypovolemic shock	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 29: Initiate an intravenous infusion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 30: Initiate a FAST 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Task 31: Establish intraosseous infusion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 32: Apply a pressure dressing to an open wound	1	2	1	1	2	1	2	2	1	0	1	1	1	1	2
Task 33: Apply a hemostatic dressing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 34: Provide basic emergency care for an amputation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 35: Apply a tourniquet to control bleeding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 36: Treat a casualty with an open abdominal wound	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0
Task 37: Treat a casualty with an impalement	1	2	1	1	1	1	1	1	0	1	0	1	1	1	1
Task 38: Treat a casualty with an open or closed head injury	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 39: Apply a cervical collar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Task 40: Immobilize the pelvis	0	1	0	1	0	1	0	0	1	0	1	0	0	0	0
Task 41: Immobilize a fracture of the arm or dislocated shoulder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0	Did not fail
1	Only failed at 24" upper
1*	Only failed at 24 in. lower
2	Failed at both upper and lower 24 in.

Table F-2.
Failed tasks by vertical space available, TPs 1 through 6.

in.	TP1	TP2	TP3	TP4	TP5	TP6
18	2,3,4,5,7,8,10,12, 13,27,30,32,33,36, 3738,40,41	2,3,6,8,9,10,12,13, 27,30,32,33,36,37, 38,40,41	2,3,4,5,6,7,8,10,12, 13,27,30,32,33,36, 37,38,41	2,3,4,5,6,7,8,9,10, 12,13,27,30,32,33, 37,38,40,41	2,3,4,5,6,7,8,9,10, 12,13,27,30,32,33, 36,37,38,40,41	2,3,4,5,6,7,8,9,10, 12,13,27,30,32,33, 36,37,38,41
19	7,8,10,12,27,30,32, 32,38,40,41	2,3,6,7,8,10,12,13, 27,30,32,33,36,37, 38,40,41	2,3,4,5,6,7,8,10,12, 13,27,32,33,36,37, 38,41	2,3,4,5,6,7,8,10,12, 13,27,30,32,33,37, 38,40,41	2,3,4,5,6,7,8,9,10, 12,13,27,30,32,33, 36,37,38,40,41	2,3,4,6,7,8,10, 12,13,27,30,32,33, 37,38,41
20	7,8,10,13,27,30,32, 33,38,40,41	2,3,6,7,8,10,12,13, 27,30,32,33,36,37, 38,40,41	2,3,4,6,7,8,10,12, 13,27,32,33,37,38, 41	6,7,8,10,12,13,27, 30,32,33,37,40,41	2,3,4,6,7,8,10,12, 13,27,30,32,33,36, 37,38,41	2,3,4,6,7,8,10, 12,13,27,30,32,33, 37,38,41
21	13,27,30,32,38	2,3,6,7,8,10,12,13, 27,30,32,33,36,37, 38,40,41	2,3,4,6,8,10,12,13, 27,32,38	7,8,10,12,13,27,30, 32,33,41	2,3,4,6,7,8,10,12, 13,27,30,32,37,38	2,3,4,6,7,8,10, 12,13,27,30,32,33, 37,38,41
22	13,27,32	6,7,10,12,13,27,30, 32,33,37,40	6,12,13,27,32	7,13,27,30,32	2,3,4,6,7,8,10,12, 13,27,32,38	12,13,27,32,37
23	13,27,32	7,12,13,27,30,32,3 3,37	6,13,27	13,27,30	2,3,4,6,7,8,12, 13,27,32,38	12,13,27,37
24	27	12,13,27,32,37	27	27	7,13,27,32	12,27
25	27	27,32	27	27	27	27
26	27	27	27	27	27	27
27	27	27	27	27	27	27
28	27	27	27	27	27	27
29	27	27	27	27	27	27
30	27	27	27	27	27	27
31	27	27	27	27	27	27
32	27	27	27	27	27	27
33	27	27	27	27	27	27
34	27	27	27	27	27	27
35	27	27	27	27	27	27
36	27	27	27	27	27	27
37	27	27	27	27	27	
24 T	27,32,37	6,13,27,32,37,40	13,27,32,36,37	7,13,27,30,32,37, 40	6,7,8,13,27,32,36, 37	7,9,13,27,32,36,37, 40

Table F-3.
Failed tasks by vertical space available, TPs 7 through 12.

in.	TP7	TP8	TP9	TP10	TP11	TP12
18	2,3,4,6,7,8,10,12, 13,27,30,32,33,36, 37,38,41	2,3,4,5,6,7,8,10,12, 13,27,30,32,33,36, 37,38,40,41	2,3,4,6,7,8,9,10,12, 13,14,27,30,32,33, 38,40,41	2,3,4,5,6,7,8,10,12, 13,27,30,32,33,37, 38,41	2,3,4,5,6,7,8,10,12, 13,27,30,32,33,36, 37,38,40,41	2,3,4,6,7,8,10,12, 13,27,32,33,36,37, 38,40,41
19	2,3,4,6,7,8,10,12, 13,27,30,32,33,36, 37,38,41	2,3,4,5,6,7,8,10,12, 13,27,30,32,33,36, 37,38,40,41	2,3,4,6,7,8,10,12, 13,27,30,32,33,38, 40,41	2,3,4,6,7,8,10,12, 13,27,32,33,37,38, 41	2,3,4,6,7,8,10,12, 13,27,30,32,33,36, 37,38,40,41	2,3,4,6,7,8,10,12, 13,27,32,33,37,38, 41
20	2,3,4,6,7,8,10,12, 13,27,30,32,33,37, 38,41	2,3,4,6,7,8,10,12, 13,27,30,32,33,37, 38,40,41	2,3,4,6,7,8,10, 13,27,30,32,33,38, 40,41	2,3,4,6,7,8,10,12, 13,27,32,33,38,41	2,3,4,6,7,8,10,12, 13,27,32,33,37,38, 40,41	2,3,4,6,7,8,10,12, 13,27,32,33,38,41
21	2,3,4,6,7,8,10,12, 13,27,30,32,33,37, 38,41	2,3,4,6,7,8,10,12, 13,27,30,32,37,38	2,3,4,6,7,8,10, 13,27,30,32,33,38, 40,41	2,3,4,6,7,8,13,27, 32,38	2,3,4,6,7,8,10,13, 27,32,33,37,38,41	2,3,4,6,7,8,10,12, 13,27,32,33,38,41
22	6,7,10,13,27,32,33, 41	2,3,4,6,7,8,10,12, 13,27,30,32,38	2,3,4,6,7,8,10, 13,27,30,32,33,38, 41	13,27, 32	2,3,4,6,7,8,10,13, 27,32,33,38,41	6,12,13,27,32,33, 41
23	6,13,27,32	2,3,4,6,7,8,12, 13,27,32,38	2,3,4,6,7,8,27,30	13,27	13,27,32,41	13,27
24	27,32	7,27,32	7,27	27	27	27
25	27	27	7,27	27	27	27
26	27	27	27	27	27	27
27	27	27	27	27	27	27
28	27	27	27	27	27	27
29	27	27	27	27	27	27
30	27	27	27	27	27	27
31	27	27	27	27	27	27
32	27	27	27	27	27	27
33	27	27	27	27	27	27
34	27	27	27	27	27	27
35	27	27	27	27	27	27
36	27	27	27	27	27	27
37	27	27	27			27
24 T	6,27,32,36,37	7,27,32,37	6,7,9,27,30,32,40	13,27,37	27,32,40	13,27,32,37

Table F-4.
Failed tasks by vertical space available, TPs 13 through 15.

in.	TP13	TP14	TP15
18	2,3,4,5,6,7,8,9,10, 12,13,27,30,32,33, 36,37,38,40,41	2,3,4,5,6,7,8,9,10, 12,13,27,30,32,33, 36,37,38,40,41	2,3,4,5,6,7,8,9,10, 12,13,27,30,32,33, 36,37,38,40,41
19	2,3,4,6,7,8,9,10, 12,13,27,32,33,36, 37,38,40,41	2,3,4,5,6,7,8,10, 12,13,27,32,33,36, 37,38,40,41	2,3,4,6,7,8,10, 12,13,27,30,32,33, 36,37,38,41
20	2,3,4,6,7,8,10, 12,13,27,32,33,38, 40,41	5,7,10,12,13,27,32, 33,36,37,38,40,41	2,3,4,6,7,8,10, 12,13,27,30,32,33, 37,38,41
21	6,7,10,12,13,27,32, 38	7,12,13,27,32,33, 36,37,38,41	6,7,12,13,27,30,32, 37,38
22	6,12,13,27,32	12,13,27,32,37	6,7,12,13,27,32
23	13,27,32	13,27,37	13,27,32
24	27	27	27,32
25	27	27	27
26	27	27	27
27	27	27	27
28	27	27	27
29	27	27	27
30	27	27	27
31	27	27	27
32	27	27	27
33	27	27	27
34	27	27	27
35	27	27	27
36	27	27	27
37		27	27
24 T	27,32,37	27,32,36,37	27,32,37

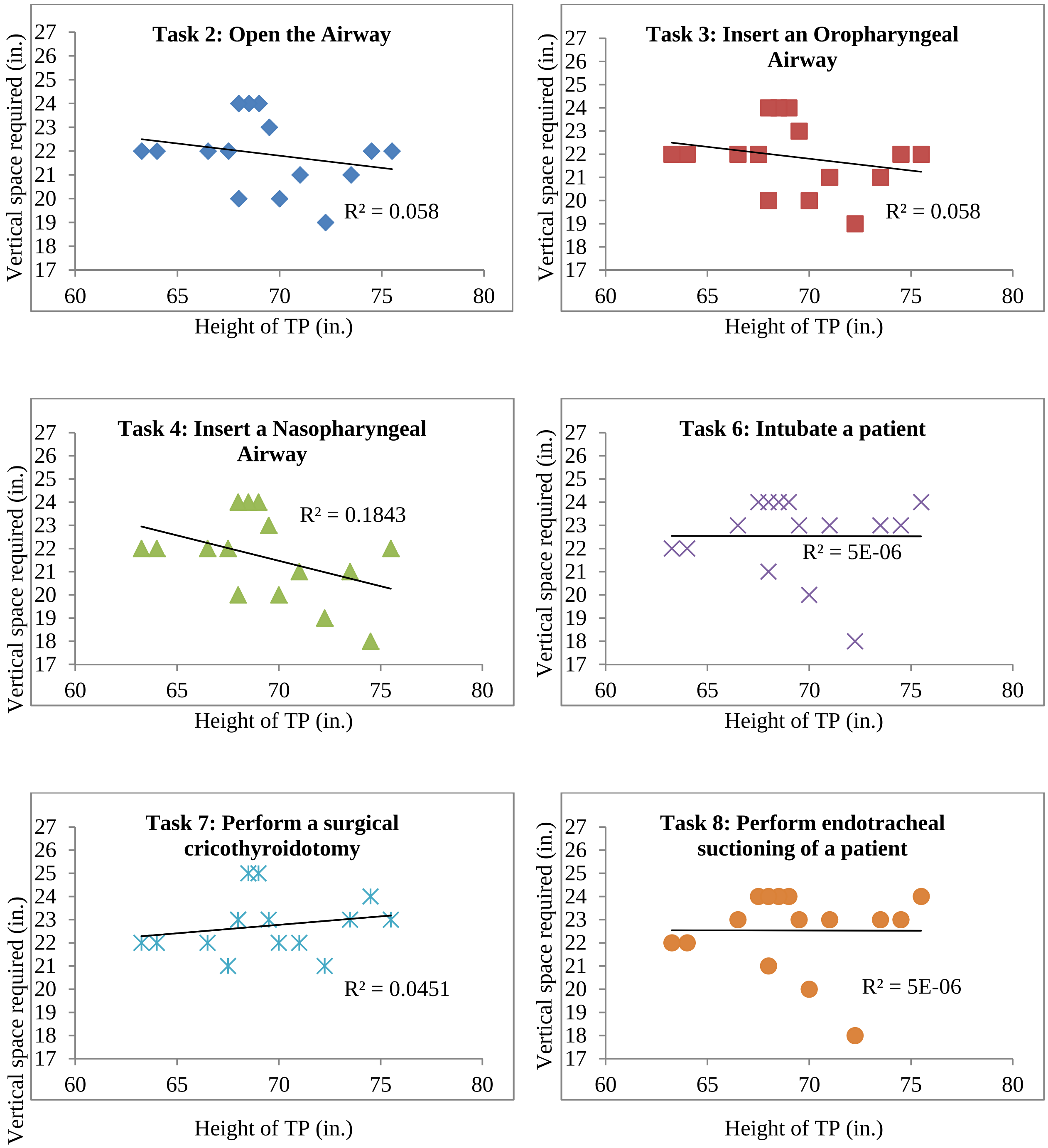


Figure F-1. Plots for successful completion of tasks height versus space available (tasks 2, 3, 4, 6, 7, 8).

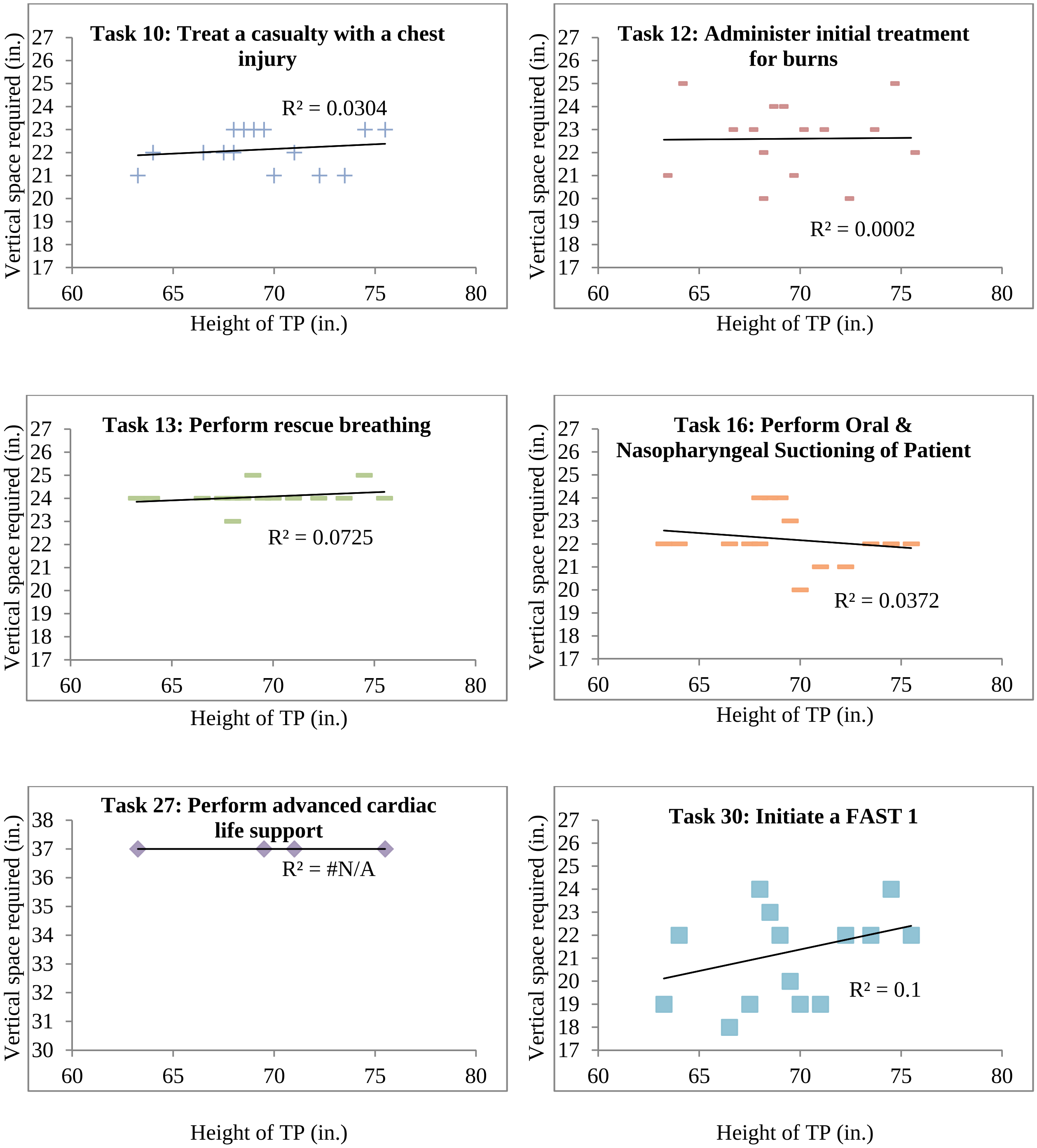


Figure F-2. Plots for successful completion of tasks height versus space available (tasks 10, 12, 13, 16, 27, 30).

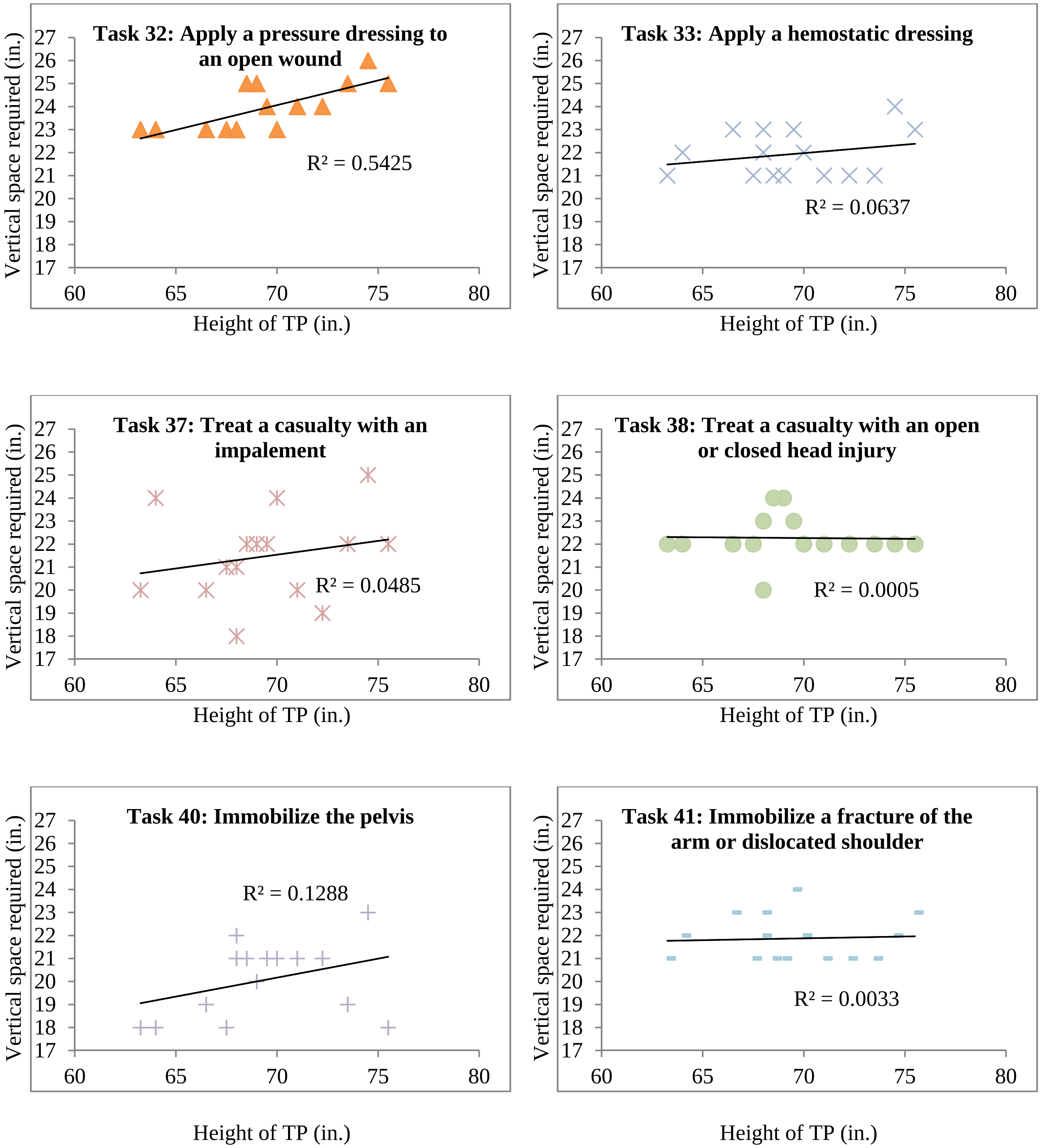


Figure F-3. Plots for successful completion of tasks height versus space available (tasks 32, 33, 37, 38, 40, 41).

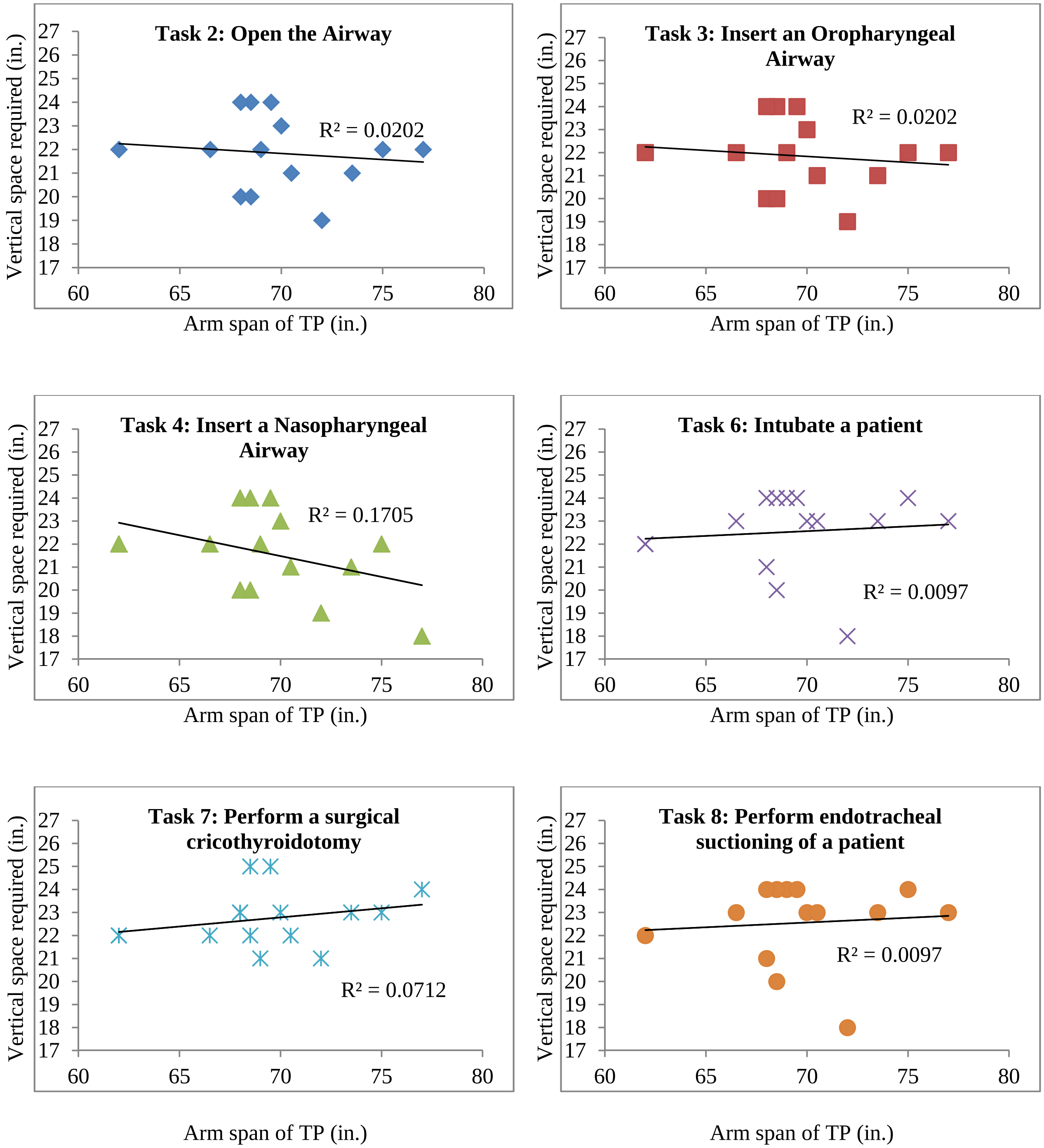


Figure F-4. Plots for successful completion of tasks arm span versus space available (tasks 2, 3, 4, 6, 7, 8).

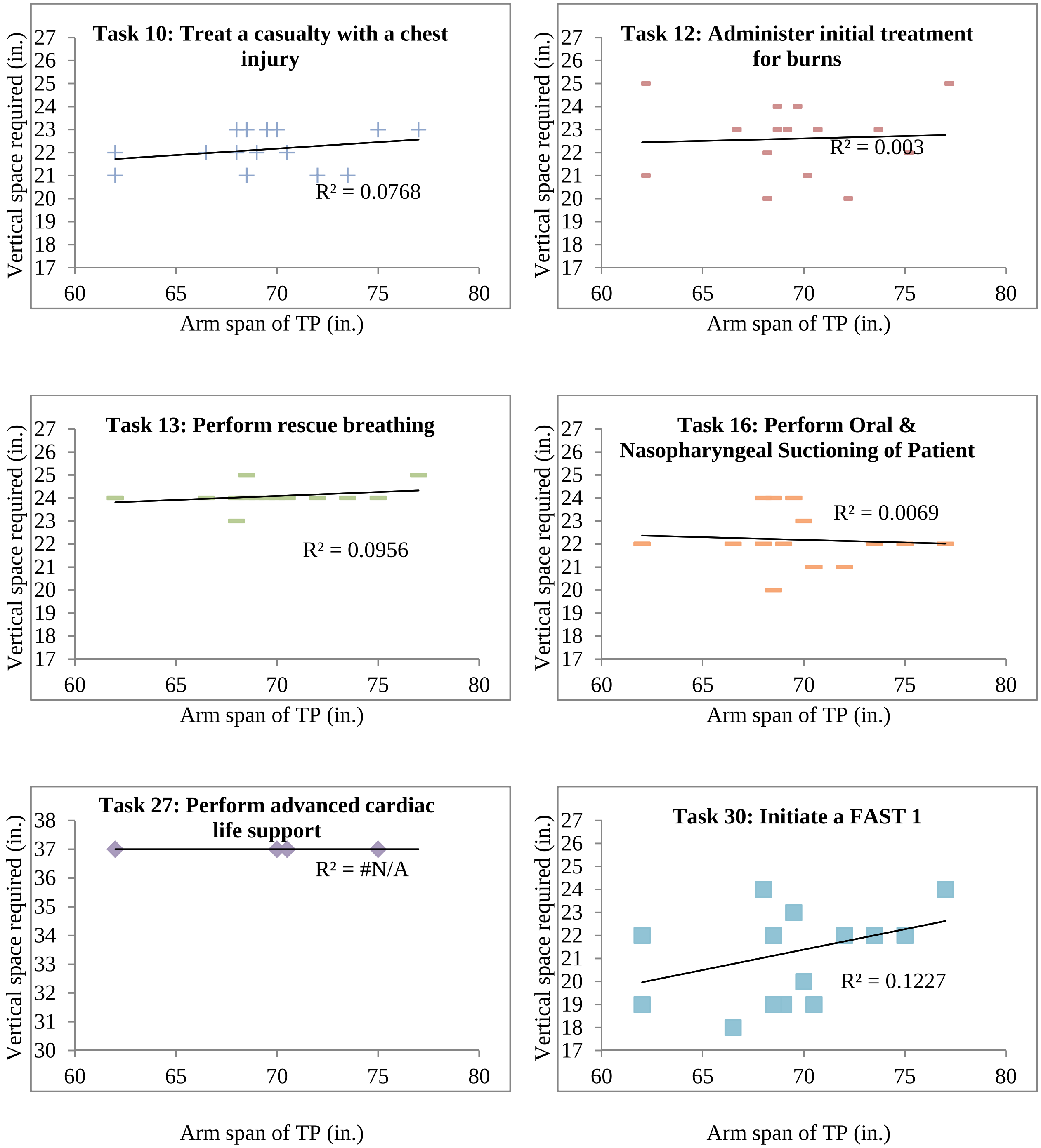


Figure F-5. Plots for successful completion of tasks arm span versus space available (tasks 10, 12, 13, 16, 27, 30).

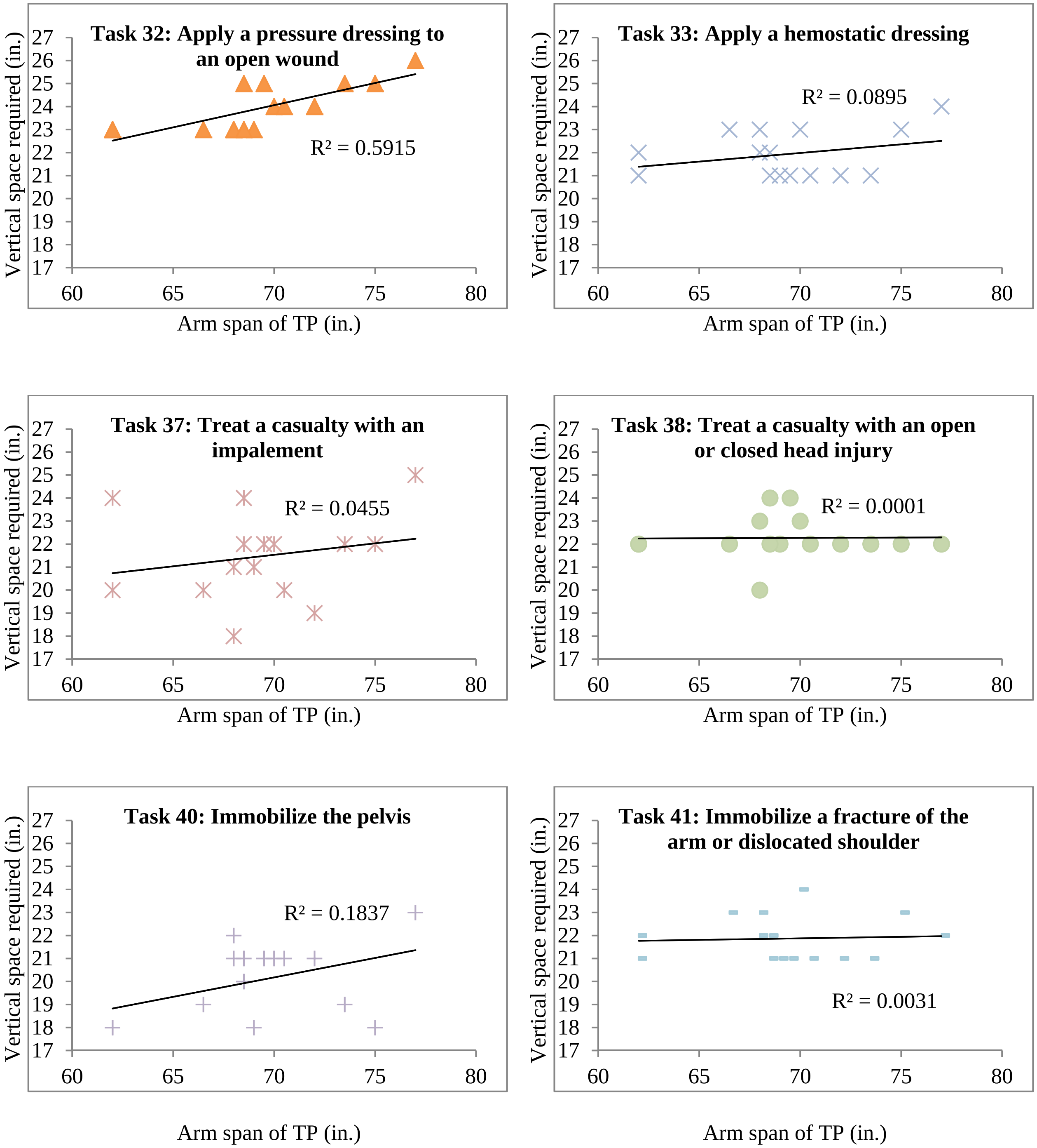


Figure F-6. Plots for successful completion of tasks arm span versus space available (tasks 32, 33, 37, 38, 40, 41).

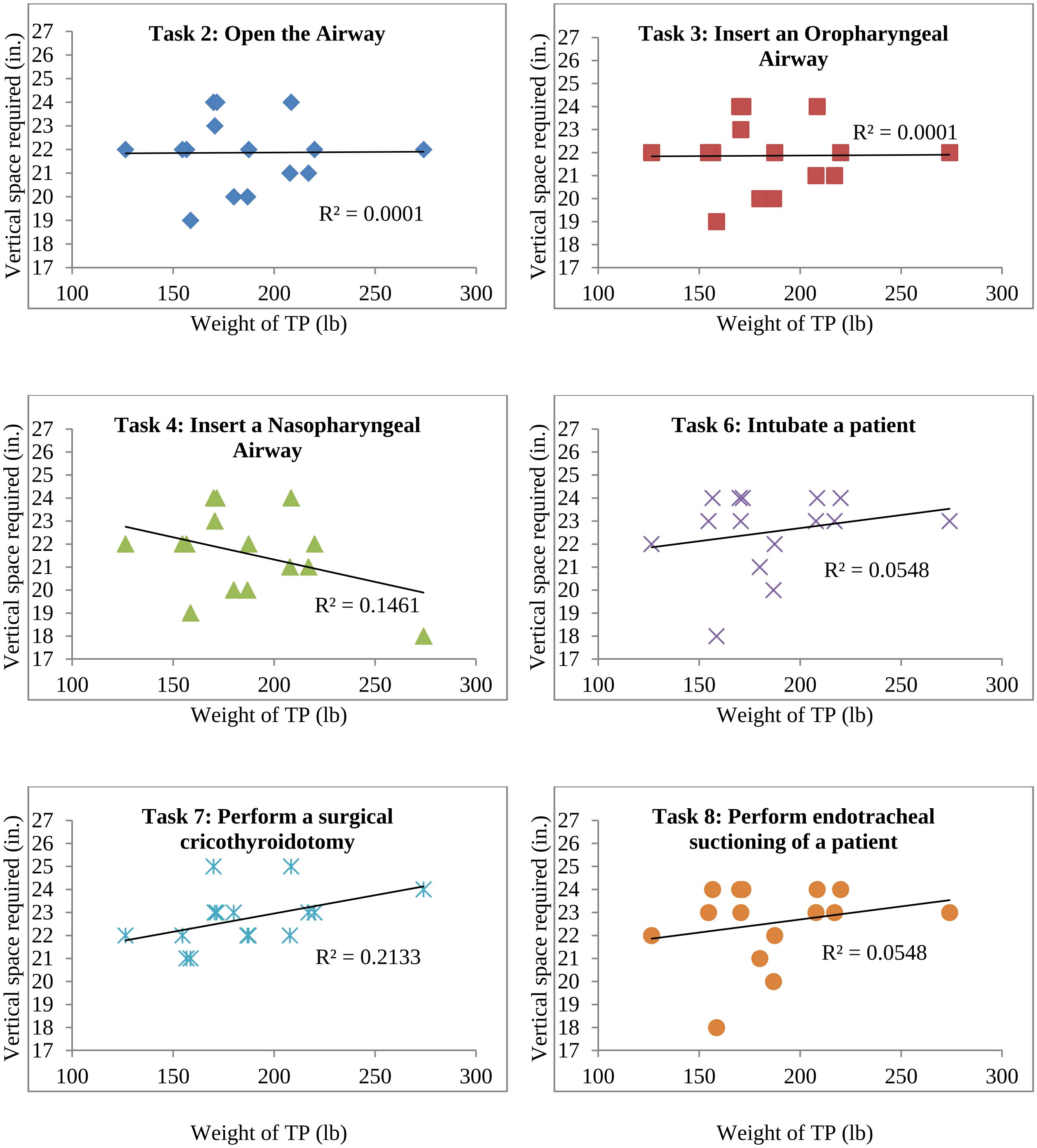


Figure F-7. Plots for successful completion of tasks weight versus space available (tasks 2, 3, 4, 6, 7, 8).

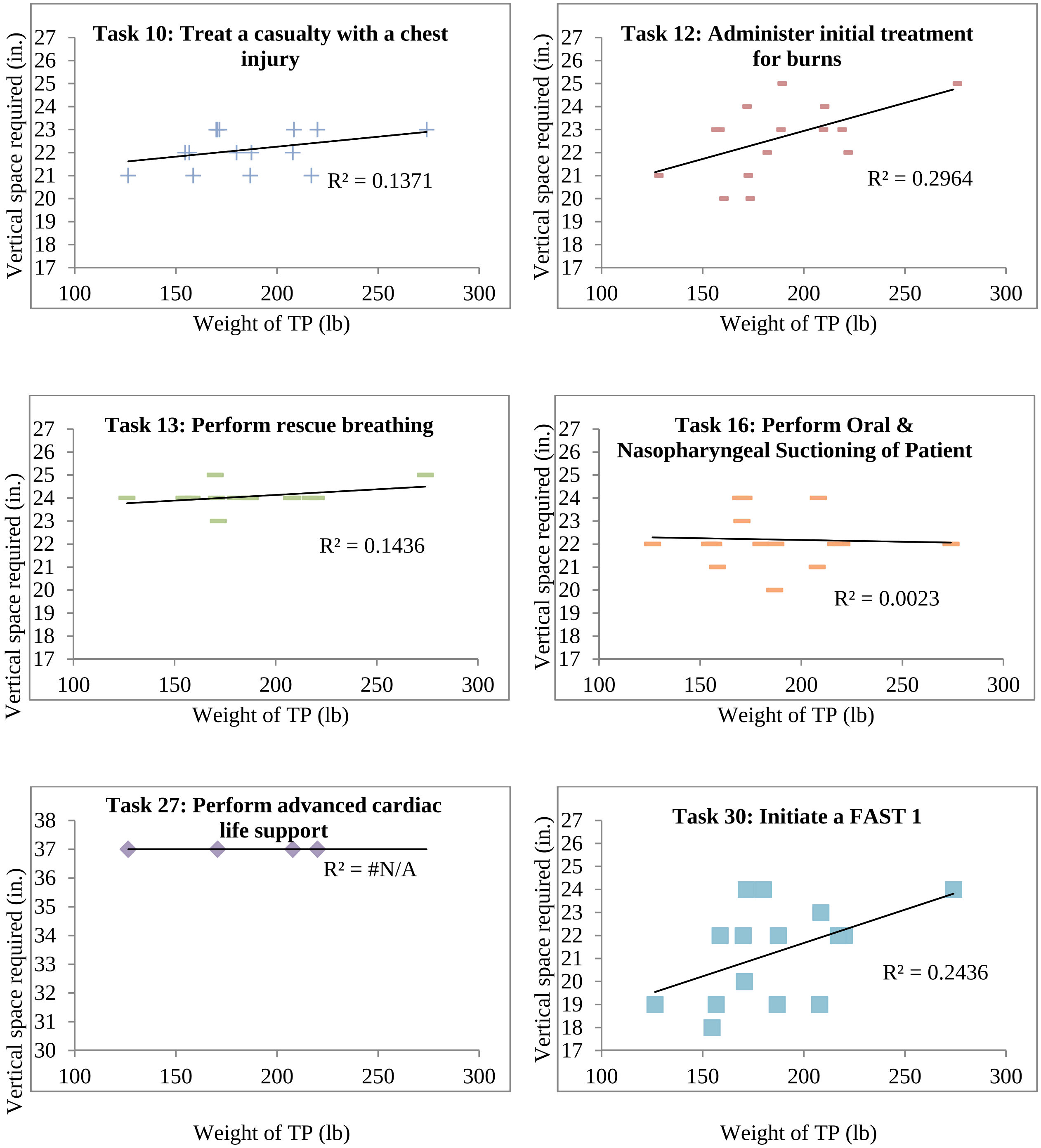


Figure F-8. Plots for successful completion of tasks weight versus space available (tasks 10, 12, 13, 16, 27, 30).

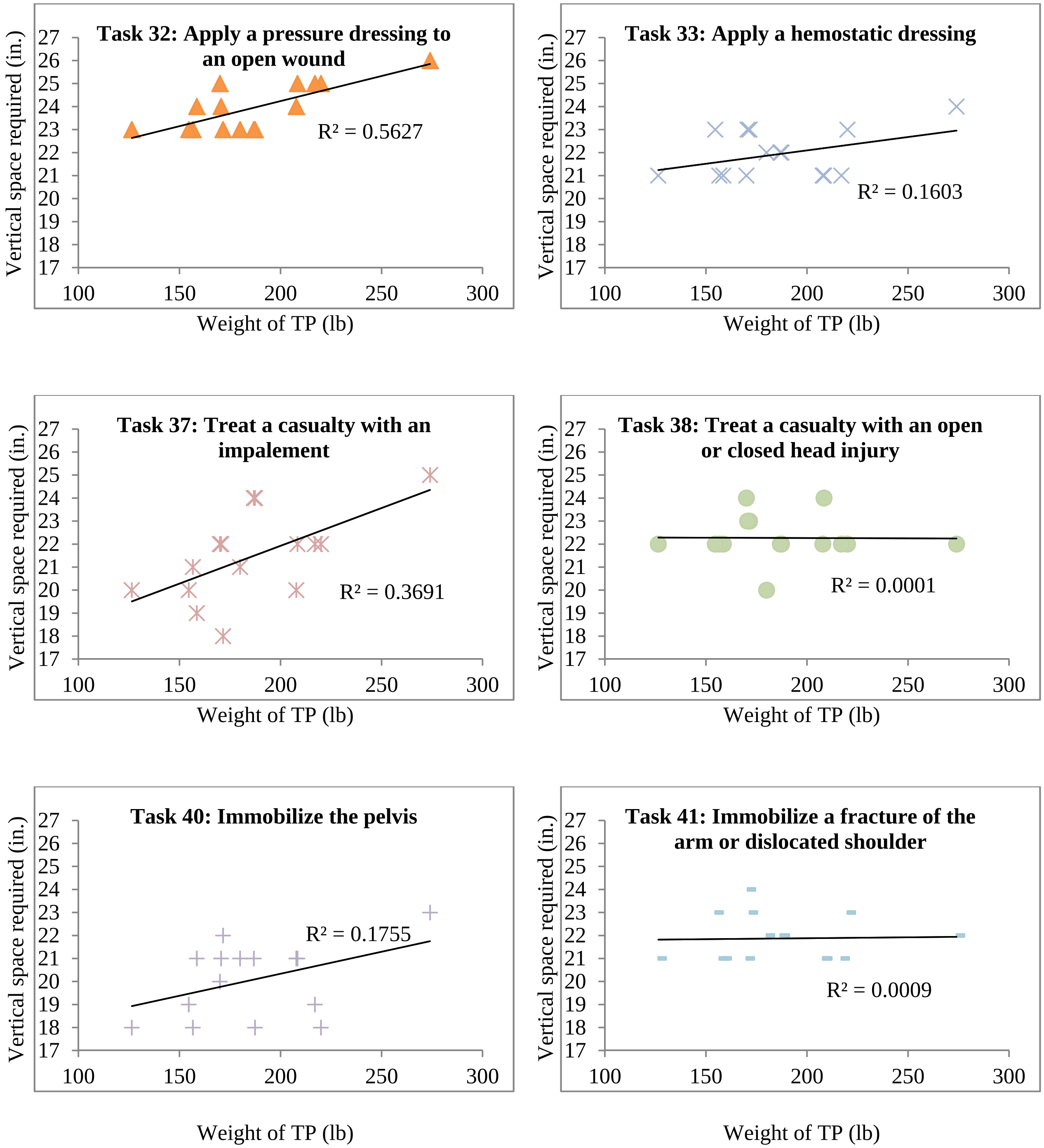


Figure F-9. Plots for successful completion of tasks weight versus space available (tasks 32, 33, 37, 38, 40, 41).

This page intentionally left blank.

Appendix G.

Chest depth percentiles from 1988 anthropometric study.

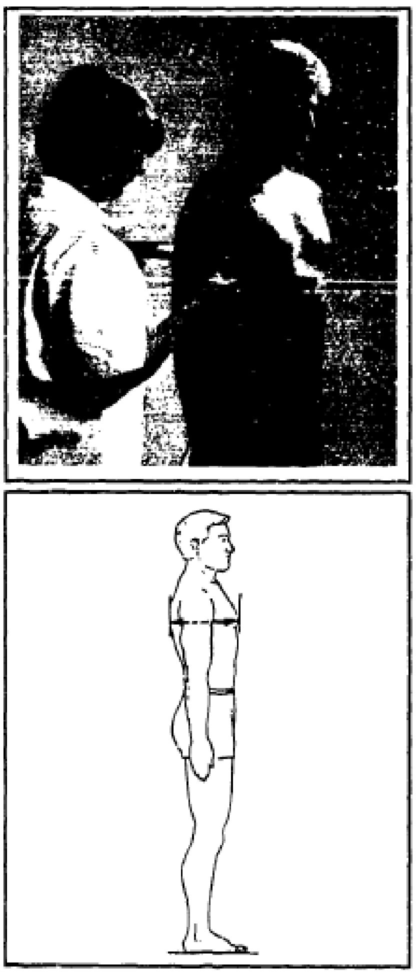
This page intentionally left blank.

Appendix G.

Chest depth percentiles from 1988 anthropometric study.

(36) CHEST DEPTH

The horizontal distance between the chest, at the level of the right bustpoint on women or the nipple on men, and the back at the same level is measured with a beam caliper. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.



THE PERCENTILES

FEMALES			MALES	
CM	INCHES		CM	INCHES
19.71	7.76	1ST	19.67	7.74
20.20	7.95	2ND	20.20	7.95
20.48	8.06	3RD	20.52	8.08
20.86	8.21	5TH	20.96	8.25
21.43	8.44	10TH	21.64	8.52
21.83	8.59	15TH	22.11	8.71
22.15	8.72	20TH	22.49	8.85
22.44	8.84	25TH	22.82	8.98
22.71	8.94	30TH	23.12	9.10
22.97	9.04	35TH	23.40	9.21
23.22	9.14	40TH	23.68	9.32
23.48	9.24	45TH	23.95	9.43
23.74	9.35	50TH	24.22	9.53
24.00	9.45	55TH	24.49	9.64
24.28	9.56	60TH	24.78	9.75
24.58	9.68	65TH	25.07	9.87
24.90	9.80	70TH	25.39	10.00
25.26	9.95	75TH	25.73	10.13
25.68	10.11	80TH	26.13	10.29
26.17	10.30	85TH	26.59	10.47
26.81	10.56	90TH	27.17	10.70
27.78	10.94	95TH	28.04	11.04
28.41	11.18	97TH	28.59	11.26
28.86	11.36	98TH	28.99	11.41
29.54	11.63	99TH	29.60	11.65

144

Figure G-1. Anthropometry for chest depth.

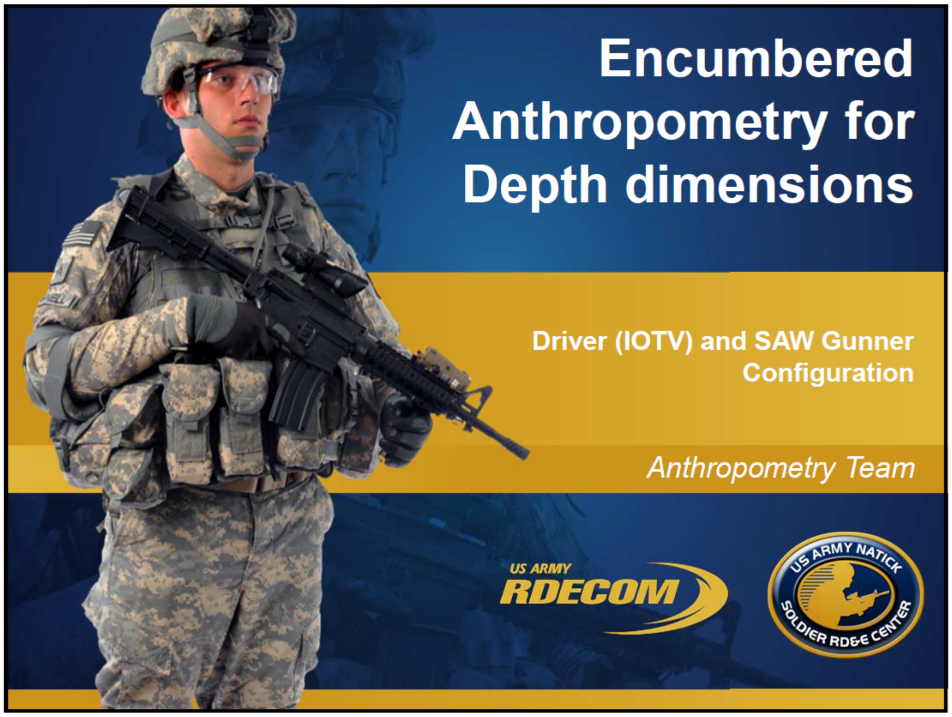
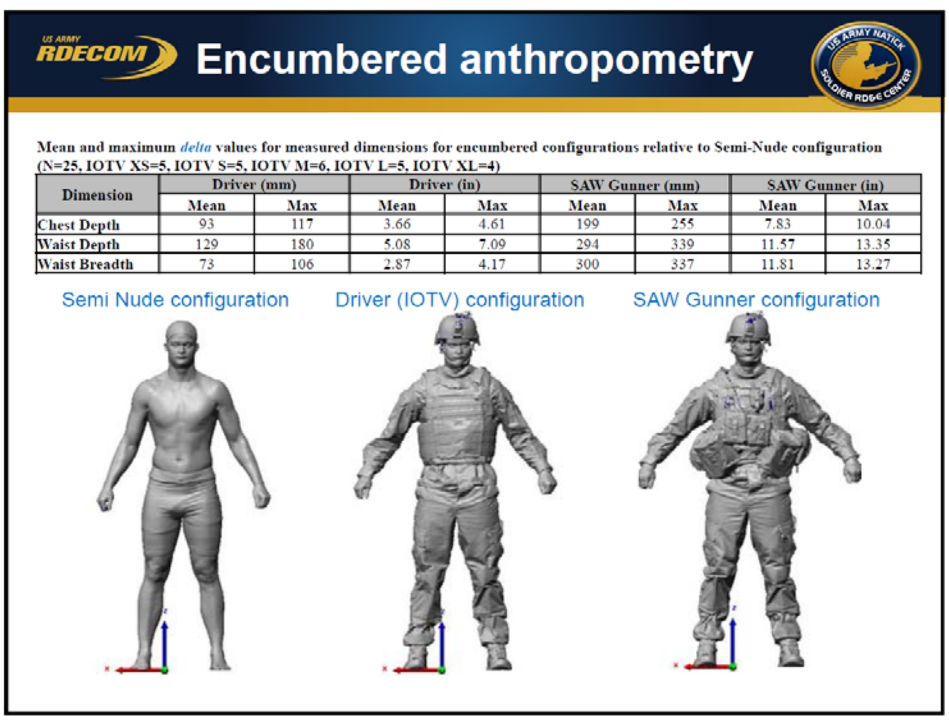


Figure G-2. Encumbered anthropometry for depth dimensions, driver, and SAW gunner.



Dimension	Driver (mm)		Driver (in)		SAW Gunner (mm)		SAW Gunner (in)	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max
Chest Depth	93	117	3.66	4.61	199	255	7.83	10.04
Waist Depth	129	180	5.08	7.09	294	339	11.57	13.35
Waist Breadth	73	106	2.87	4.17	300	337	11.81	13.27

Figure G-3. Nude, driver, and SAW gunner mean and maximum anthropometric values.

Chest Depth

- Chest Depth is the horizontal distance between the right Chest Point Anterior landmark and the back at the same level. For the encumbered measurements, the right Chest Point Anterior landmark is transferred to the CIE layers and rechecked for each configuration.

N=25	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	8 D	93 C	181 AB	199 A	176 B
Δ SD	-	7	11	26	31	20
Mean	252	259	345	432	452	428
SD	32	33	31	43	23	28
Min	198	204	303	374	414	388
25th	224	236	325	401	429	406
50th	251	257	344	430	463	423
75th	265	276	360	441	468	448
Max	335	335	433	574	488	485
Range	137	131	130	200	74	97

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

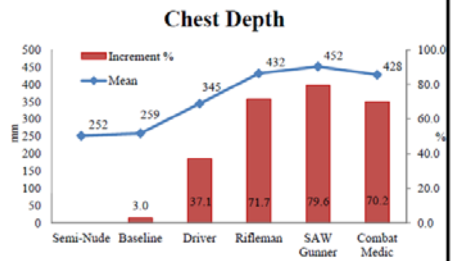


Figure G-4. Nude, driver, and SAW gunner chest depth anthropometric values.

Waist (Omphalion) Depth

- Waist (Omphalion) Depth is the horizontal distance between the front and the back of the waist at the level of the Omphalion. For the encumbered measurements, the Omphalion Point Anterior landmark is transferred to the CIE layers and rechecked for each configuration.

N=25	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	10 C	129 B	304 A	294 A	309 A
Δ SD	-	9	23	28	42	18
Mean	231	241	359	535	527	535
SD	26	28	26	26	33	34
Min	191	204	310	487	401	437
25th	212	217	339	517	512	528
50th	229	240	360	537	536	537
75th	252	261	377	547	544	550
Max	290	304	405	600	572	605
Range	99	100	95	113	171	168

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

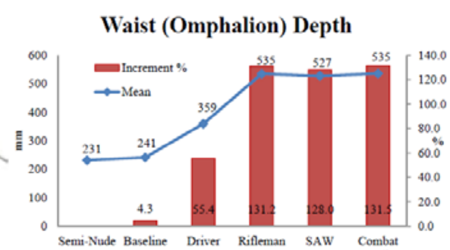


Figure G-5. Nude, driver, and SAW gunner waist depth anthropometric values.

Waist (Omphalion) Breadth

- Waist (Omphalion) Breadth is the horizontal breadth of the waist at the level of the Omphalion. For the encumbered measurement, waist landmarks are transferred from the Semi-Nude configuration to the CIE layers and rechecked for each configuration.

N=25	Semi-Nude (mm)	Baseline (mm)	Driver (mm)	Rifleman (mm)	SAW Gunner (mm)	Combat Medic (mm)
Δ from Semi-Nude	-	4 D	73 C	287 B	300 A	280 B
Δ SD	-	8	19	33	22	37
Mean	321	326	394	609	620	601
SD	36	34	24	15	20	22
Min	278	280	346	583	585	552
25th	293	298	372	602	608	587
50th	317	329	395	607	617	603
75th	343	341	409	620	628	611
Max	417	416	445	638	673	656
Range	139	136	99	55	88	104

A>B>C>D, Superscripts of different letters indicate significant differences at the p<.05 level.

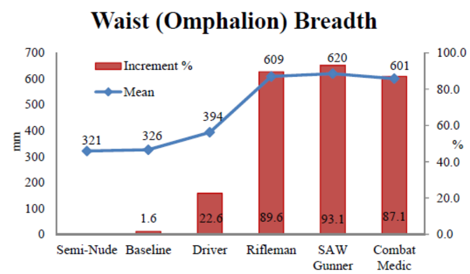


Figure G-6. Nude, driver, and SAW gunner waist breadth anthropometric values.

Department of the Army
U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama, 36362-0577
www.usaarl.army.mil

U.S. Army Medical Research and Materiel Command